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The Fern Lake Trace Mineral Metabolism Program

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ABSTRACT

The role of the mineral supplements in the management of fish ponds, game ranges, and forests has been a research subject of a host of individuals and organizations for many years. Nearly all of such projects, however, have been limited by analytical techniques that can at best be applied only to the macronutriments.

The cooperative program at Fern Lake, conducted by the U. S. Atomic Energy Commission, University of Washington and the State of Washington Department of Game, embraces studies in which the total mineral need in the ecology of the Fern Lake watershed is evaluated by the use of the techniques of the radiation biologist. Using the combined skills of the physical and biological sciences it is hoped that great progress can be made in improving the productive capacity of this impoverished watershed.

INTRODUCTION

The productive capacity of land and water areas has been the subject of investigation by many agencies and thousands of individuals for many years. Mortimer and Hickling (1954) have abstracted 351 research papers on the role of fertilizers in fishponds. The literature on artificial fertilization of lakes and ponds also was reviewed by Maciolek (1954). In forestry and farm journals repeated reference is made to the need for adding deficient elements to the soil. White and Leaf (1956) list 235 scientific periodicals in which articles on forest fertilization are published. However, in spite of the many years of effort expended in the study of the methods of application of fertilizers to land and water areas and the results obtained, there remain numerous problems to be solved, especially in the mineral-deficient, rain-leached northwest coastal region of the United States.

In 1957, studies for the trace mineral metabolism program at the Fern Lake laboratory were initiated in an attempt to apply the accumulated knowledge to the improvement of the pro-

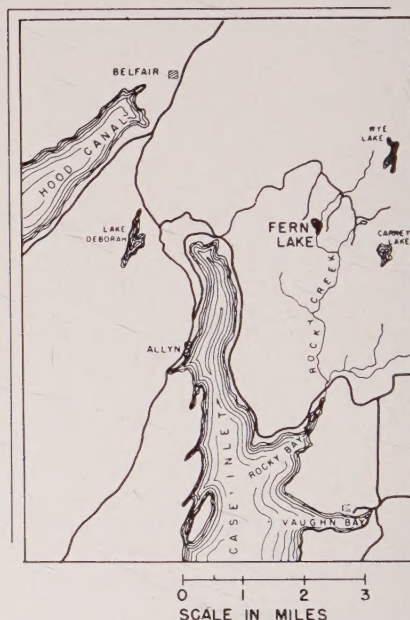
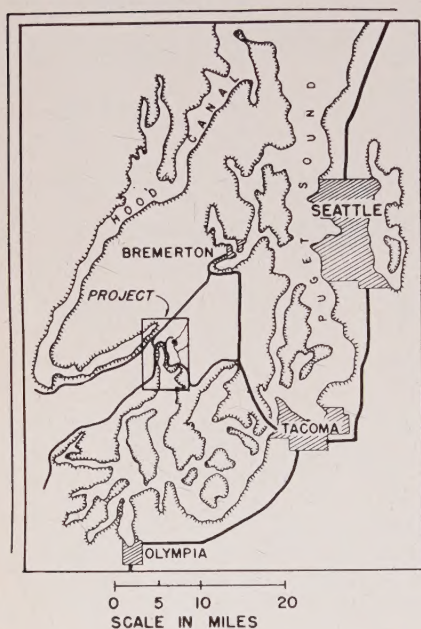
ductive capacity of land and water resources, and, through cooperative effort, to develop methods and practices which would maintain the environment by retarding "the downhill flow of nutrients from the hills to the sea" (Leopold, 1941) and accentuate the uphill movement of nutrients by natural and artificial means.

It was realized that a number of scientific disciplines and administrative agencies could contribute to the accomplishment of the broad objectives of the program. Thus, the University of Washington, the Washington State Department of Game and the U. S. Atomic Energy Commission, by pooling resources and scientific personnel in a cooperative team effort, have and are making a positive contribution to the progress of the program.

In organizing the research effort for the Fern Lake laboratory, the University of Washington, under the general supervision of the Dean of the Graduate School, provides the laboratory facilities and scientific skills for a portion of the program; the Washington State Department of Game has made available the lake and its watershed as well as the necessary buildings and the essential management experience; and the U. S. Atomic Energy Commission provides financial support, special equipment and skills in the new methods of isotopic research.

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FERN LAKE

KITSAP COUNTY, WASH.

SEC. 10 T. 22 N. R. 1 W.

AREA 18.9 ACRES

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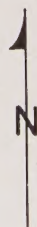
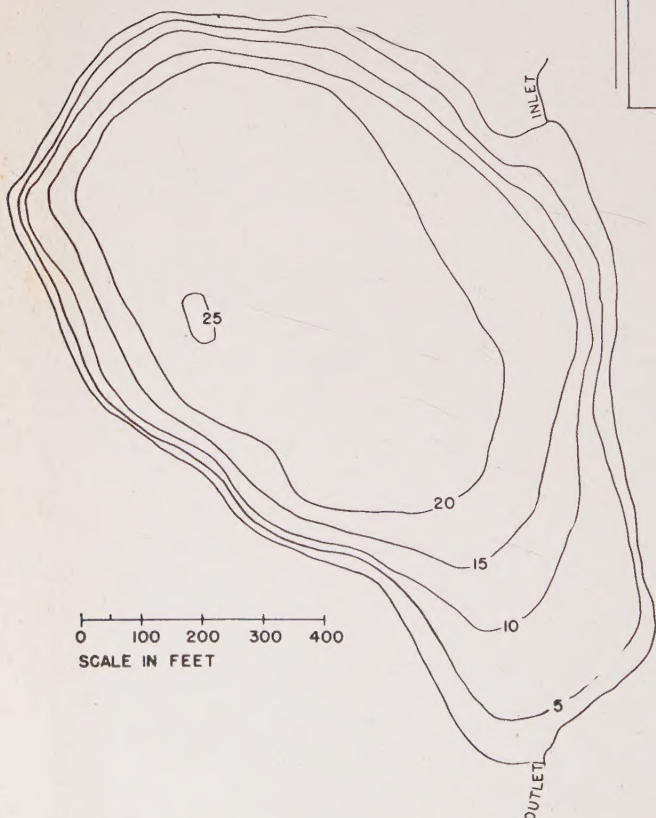


FIGURE 1.—Map of Fern Lake and environs.

The field station for the laboratory at Fern Lake is about 50 miles southwest of Seattle (Figure 1). Fern Lake is an 18.9-acre lake containing 12,856,500 cubic feet of water. A small creek, Rocky Creek, flows through the lake and into Rocky Bay, an arm of Puget Sound. Rocky Creek has a minimum flow of 3.49 cubic feet per second. Extreme flows in Rocky Creek, where it enters Rocky Bay, may range from 39 cubic feet per second every 3 years, to 64 every 10 years and 91 cubic feet per second as frequently as every 20 years.

The Fern Lake drainage basin of 2.8 square miles is largely uninhabited. The soil is poor and growth is slow, although the region is forest covered (Figure 2). The only economic resource of the watershed is the production of Christmas trees, greenhouse supplies of ferns, salal and evergreen huckleberry brush.

The geology of the Fern Lake area has been studied under the supervision of Professor J. D. Parksdale. In a preliminary report on the geology Palmer (1959) emphasizes the glacial origin of the area:

forms and deposits around Fern Lake which has itself been formed in a depression molded by the base of a glacier.

Repeated movement and washing of the land mass by glacial action left a layer of unproductive soil. Since the retreat of the glaciers, vegetation has returned and soil weathering and organic matter have accumulated to form pockets of soil in the low areas. Peat deposition in depressions in the glacial drift began sometime after the glaciers had receded. Radiocarbon dating of the earliest depositions of peat has established a minimum of $13,650 \pm 550$ C¹⁴ years' time since the retreat of the Vashon glacier (Rigg and Gould, 1957).

The ecological history of the Fern Lake watershed since the retreat of the glaciers and the development of the forest cover, with a detailed study of recent trends, has been reported by Boardman³. The early forest history was traced through sedimentary columns taken from bogs. More recent changes were traced back to about 275 years ago from studies of ring counts on tree stumps. The area has been subjected to occasional forest fires, with an average of two each hundred years. During 1928-1929 the watershed was clear-cut logged and then burned. Since the logging and burning, the dominant tree in the watershed is the Douglas fir (*Pseudotsuga menziesii*), many of which are marketed as Christmas trees, usually when they are less than ten feet tall. In addition to the Douglas fir stands, western red cedar, lodgepole and white pine, alder, and western hemlock are of some commercial importance. Boardman lists a total of 65 native plants common to the drainage basin.

RESEARCH PROGRAM

The study program for the Fern Lake watershed has been planned as a 10-year operation. The first two years are to be devoted to establishing the physical and biological inventories to be used as the bases for the subsequent studies in trace mineral metabolism.

In addition to the geological and forest ecology surveys that have been mentioned, studies are under way on soil mapping, chemical composition, deficiency elements and leach-

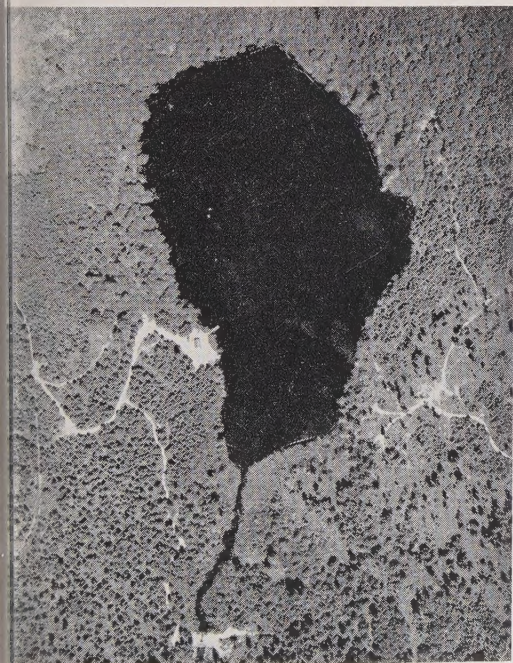


FIGURE 2.—Aerial photograph showing Fern Lake and adjacent area.

(State of Washington Department of Game photo)

Fern Lake is situated in the Puget Sound lowland and underlain by approximately 500-700 feet of unconsolidated glacial and non-glacial deposits. Glaciation has played a dominant role in forming the land

³ Boardman, Robert. 1958. An ecological description of the Fern Lake watershed. M. F. (Forestry) thesis, Univ. Washington Library.

ing rates of the various soil types. Associated with the soils study a microecology program of soil-plant relationship also has been started.

The watershed receives an annual rainfall of about 50 inches, almost all of which occurs during the winter season; the three summer months often are so dry that lack of moisture is a limiting factor to the growth and survival of all but the hardiest forms. A portion of the rainfall runs off as surface water; the rest seeps through the porous, gravelly soil, upwelling as spring flows lower down the watershed. This ground water helps to stabilize the water temperatures in Fern Lake and Rocky Creek.

The original fish population in the watershed of silver salmon (*Oncorhynchus kisutch*), cut-throat trout (*Salmo clarki clarki*) sticklebacks (*Gasterosteus aculeatus aculeatus*) and reddsides (*Richardsonius balteatus*) was modified during the early part of this century by the introduction of yellow perch (*Perca flavescens*), largemouth bass (*Micropterus salmoides*), crappies (*Pomoxis nigromaculatus*)

and bullheads (*Ameiurus melas*).

In the fall of 1957, Fern Lake was treated with 1 p.p.m. of rotenone to remove all fish. While the water in the lake remained toxic a 4-foot stop dam with an 8-foot apron below (Figure 3) was constructed in the outlet creek to prevent undesirable fish from re-entering the lake from Rocky Creek. A downstream trapping device was built into the outlet stop dam to live-trap migrant fish as they leave the lake. To prevent the fish in Fern Lake from migrating up the upper portion of Rocky Creek where they would be lost in the receding water during the dry season, a stop apron was built in the inlet creek.

On May 15, 1958, twenty thousand steelhead trout (*Salmo gairdneri*) weighing 500 to the pound were planted into Fern Lake. To sample the trout population in the lake a live trap was constructed. After three months in the lake the trout fry had grown to 11.3 centimeters in total length and averaged 17.5 grams or 26 fish to the pound. The total production



FIGURE 3.—Photograph showing stop dam across Rocky Creek at the outlet of Fern Lake. This dam serves to maintain the lake level and retard upward migration of fish. A collecting trap for downstream migrant fish adjacent to the stop dam is under construction. (Photo by James O. Sneddon, University of Washington.)

of steelhead trout in the lake will be determined when the fish migrate to sea during the spring months of 1959 and 1960.

In addition to the direct measurement of the productivity of the lake as determined by the number and weight of steelhead trout migrants produced, other biological records are obtained on a continuous or weekly sample basis. Inverted cone, aquatic insect traps 1 meter in diameter are operated in the lake. These traps are lifted once a week and the insects collected are counted to give a qualitative and quantitative measurement of the aquatic insect population. Plankton samples are obtained biweekly by pumping 1000 gallons of water through a plankton net. The weight, number and kinds of organisms are determined.

Continuous records are obtained of the rainfall, humidity, air temperature, amount and duration of sunlight, water temperature at the surface, at 10 feet, and at the bottom of the lake, as well as of light penetration into the lake water.

Samples of water are taken biweekly for water chemistry. The samples are analyzed for oxygen content, pH, total solids, loss in weight on ignition, fixed residue, total hardness, alkalinity, acidity, and the amounts of magnesium, calcium, phosphorous, sulphate, chloride, silica, and nitrogen present.

After the basic studies of the ecology of the watershed are well established, the emphasis of the program gradually will be shifted to experiments to modify the environment to make it more productive. Deficiency elements in the soil and water will be added to test plots where the results may be measured in increased production of plants and animals.

In addition to the measurements of production as determined by the indicator species of plants and animals, it is desirable to follow the physical and biological cycles of both the macro- and micronutritive elements in the ecology of the watershed. Very minute amounts of the radioactive form of the elements under study will be added to the nutritive elements to label or tag the particular element used, thus making it possible to identify and follow the nutritive materials in the biological cycle, even in trace amounts.

In the vast stretches of the Pacific Ocean, in and near the Eniwetok Test Site in the Marshall Islands, it has been possible to identify and follow trace amounts of radioactive elements that are released into the water or that fall upon the atolls and islands.

During the 1954 weapons testing series at the Eniwetok Test Site, radioactive materials fell upon Rongelap Atoll in the eastern Marshall Islands. The identification and measurement of the radionuclides incorporated into the biotic cycle have been the subject of a number of research papers, (Applied Fisheries Laboratory, 1955a and 1955b). These studies, supplemented by oceanographic research in which the movement of the radioactive elements in the sea was traced, definitely have shown that the elements which enter the biological cycle do not dilute uniformly into the sea, but once incorporated into the living material move very little or at a much reduced rate when compared to the surface current drift (Harley, 1956; Donaldson *et al.*, 1957; Seymour *et al.*, 1957; Lowman *et al.*, 1957).

The Eniwetok Test Site experiments also have provided an excellent training ground for personnel and an ideal area for the development of the basic concepts and methods of procedure that may be applied to problems of trace mineral metabolism, such as those to be studied at the Fern Lake research station.

For many years fisheries management specialists have wondered about the "uphill" movement of essential nutritive elements by the migration of mature salmon from the sea to their spawning grounds. After the death of the spawned-out salmon how long does the nutritive material so-produced remain in the biotic cycle before being leached out of the soil, the creek beds or the lakes and returned "downhill" to the sea. By using a tag for the specific element or mixture of elements under investigation it will be possible to follow the biological cycling, to determine the amount of the trace elements required, and the optimum season to add the supplements.

It is hoped that by team effort botanists, foresters, ecologists, soils chemists, geologists, limnologists, meteorologists, fisheries and game management specialists, and many other workers in special fields, collectively, can evolve a study that will be a real contribution to an improved animal and plant environment.

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Fish Populations of Backwater Lakes in Louisiana

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ABSTRACT

Fish populations in seven backwater lakes were sampled by rotenone poisoning. On the average, 397 pounds of fish per acre comprising 103 pounds of game fish and 169 pounds of commercial fish were recovered from the lakes. Recoveries from individual lakes ranged from 142 to 651 pounds of fish per acre. Non-predaceous fish made up 56 percent of the total population. Bluegill sunfish, warmouth sunfish, gizzard shad, fresh-water drum, large-mouth bass, black crappie and spotted gar were the principal fishes in the lakes. An average of 78 pounds of available game fish (harvestable-size game fish) per acre was recovered from the lakes. Fairly large concentrations of fish occurred in relatively small areas in some of the backwater lakes. A total of 974 pounds of fish, of which 475 pounds were game fish, was recovered from a single 1-acre sampling area.

On the average, there were 1.9 pounds of non-predaceous fish per pound of predaceous fish. There were considerably less available forage fish (by weight) for the predators than they themselves made up in the population. The predaceous fish in the backwater lakes must be partly dependent on some type of forage other than fish, and swamp crayfish are probably important in their diet.

A large increase in the area of the lakes during high water periods in the spring creates a favorable habitat for a rapidly expanding fish population. The quality of the sport fishing on the backwater lakes is excellent.

INTRODUCTION

The present study was undertaken to gather basic data on populations of fish in Louisiana backwater lakes since little was known about the species composition or size of such populations. Backwater lakes in Louisiana support extensive sport and commercial fisheries.

The major backwaters of Louisiana are located in the flood plain areas of the Mississippi, Red, Black and Atchafalaya Rivers (Figure 1). Less extensive backwaters are found along smaller streams such as the Ouachita and Pearl Rivers. The flood plains are dissected by an intricate system of large numbers of shallow lakes of various shapes and sizes. During periods of high water, the lakes receive backwater directly or indirectly from nearby streams. The flood plains are quite level and consequently during periods of high water large expanses of land which are normally dry are flooded. The majority of the backwater areas shown in Figure 1 are not permanent water bodies; however, most of these areas are subject to frequent flooding from a depth of a few inches, to as much as

30 feet or more. Most high water stages occur during late winter, spring and early summer; however, the depth and extent of flooding varies from year to year and from lake to lake.

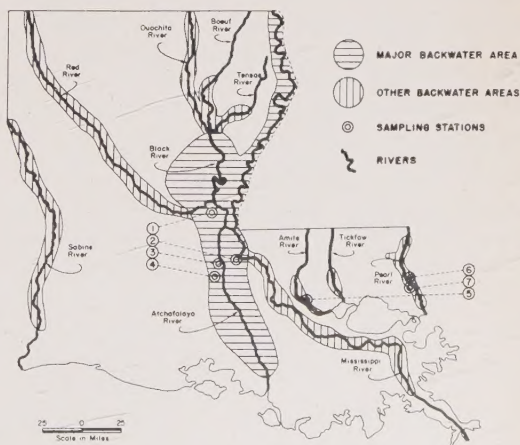


FIGURE 1.—Louisiana, showing location of backwater areas containing backwater lakes and the sampling stations where fish were taken by rotenone. Stations are numbered in the order that they are listed in Table 1.



FIGURE 2.—A typical Louisiana backwater lake. Photo by Ben Leeper, Remington Rand Corporation.

The majority of the permanent water bodies are rather shallow during the low water periods and most lakes have average depths of less than 15 feet. Most of the lakes are not very large—the majority of them are less than 5 thousand acres in area.

Aquatics — coontail (*Ceratophyllum* spp.), najas (*Najas* spp.), pondweed (*Potamogeton* spp.), etc.—are abundant in some of the lakes; however, in others they are absent. Depth and other physical characteristics of the lakes seem to influence the abundance of aquatics. Also, the depth and extent of the high water stages during spring seem to exert considerable influence on their abundance. During years when flooding is less extensive and severe, aquatics are much more abundant.

Dead trees, logs and stumps which were killed by flooding are numerous in most of the lakes. Also, scattered stands of live trees and shrubs which tolerate permanent flooding, such as bald cypress (*Taxodium distichum*), tupello

gum (*Nyssa aquatica*) and button bush (*Cephalanthus occidentalis*), are common. Figure 2 shows a typical Louisiana backwater lake.

The land not permanently flooded supports a luxuriant growth of herbaceous and woody plants. Much of the higher land supports extensive stands of hardwood timber while land which doesn't dry out until late in the summer supports thick growths of herbaceous plants interspersed with stands of trees which tolerate considerable flooding, such as bald cypress, black willow (*Salix nigra*) and water elm (*Planera aquatica*).

The majority of the backwater lakes were formed by a fluvial action; however, a few of them are man-made or have been modified to some extent by man. The most common modification consists of low-water dams on the outlets to keep a minimum water level or to prevent the lakes from going completely dry during low water periods. Hutchinson (1957)

classified lakes as to their origin and describes the processes involved in their formation. Most of the backwater lakes would fall under his class: Lakes of Mature Flood Plains—including his Type 55 — oxbows or isolated loops of meanders, Type 56 — lakes in depressions formed on flood plains by uneven aggradation during floods, Type 57 — lakes in abandoned channels, Type 58 — lateral level lakes lying between a levee and the scarp defining the flood plain and Type 59 — crescentic lakes formed between levees along meander loops which have occupied a series of different positions.

MATERIALS AND METHODS

Fish population sampling

Fish populations in seven backwater lakes (Table 1) were sampled by rotenone poisoning. Practically all of the 17 sampling areas were 1 acre in size. The bodies of water sampled, dates of sampling and the number of sampling areas are given in Table 1. Since the lakes were rather shallow (mostly less than 7 feet in depth), it was possible to sample nearly all areas in the lakes. All sampling was done during periods of low water. The sampling areas were surrounded by a 1 inch square-mesh net, and for the most part, the "block-net" described by Lambou and Stern (1958) was used. Three pints of five percent emulsifiable rotenone per acre foot of water was applied by pumping the solution through a perforated hose. It was calculated that this would give a concentration of approximately 1 ppm. Fish were recovered over a 12 day period and every possible effort was made to pick up all, including small, fish.

Analysis of Data

Recovery from each sampling area was converted to pounds of fish per acre so that each sample obtained from a body of water would be given equal weight. Mean values for each body of water were then determined. Each body of water being considered separately, using the means for the seven lakes for pounds of fish per acre, percent composition, etc., the general mean value for each index was determined.

The fish recovered were separated into two main groups—non-predaceous and predaceous. The non-predaceous fish include those types of fish that normally do not feed on smaller fish, while predaceous fish are those that usually feed on other fish and large forage animals. This grouping is similar to Swingle's (1950) forage and carnivorous or piscivorous grouping. Predaceous and non-predaceous species as here considered are shown in Table 2.

All species of fish that sportsmen normally fish for were grouped under the heading of game fish. Available game fish (harvestable-size game fish) are those that I considered to be of a size large enough to be creelied by sport fishermen. Since there is no size limit on game fish in Louisiana, any minimum size assigned to a species of fish is arbitrary. Game fish and their minimum available sizes are shown in Table 2.

All species of fish that are regularly or occasionally sold commercially were grouped under the heading of commercial fish. Some of these fishes are not of much value commercially while others support large and extensive commercial fisheries. Available commercial fish are those of a size that can be sold legally. If a species had no minimum size limit, all sizes were considered as being available. Commer-

TABLE 1.—Louisiana backwater lakes in which fish populations were sampled by rotenone.

Key Number	Name	Location (Parish)	Approximate size (acres)	Approximate average depth in feet (during low water stages)	Dates samples were taken	Number of samples
1	Spring Bayou Backwater...	Avoyelles.....	1,500	4	September, 1954	4
2	Old River.....	Pointe Coupee..	4,100	15	August, 1955	3
3	Bayou Courtableau Pitts...	St. Landry.....	50	6	August, 1954	1
4	Bayou Courtableau.....	St. Landry.....	700	15	August, 1954	2
5	Colyell Bay.....	Livingston.....	250	10	July, 1954	2
6	Pearl River Backwater.....	St. Tammany....	100	7	May-June, 1954	3
7	Dubloon Bayou.....	St. Tammany....	30	7	July, 1954	2

TABLE 2.—Species of fish taken from seven Louisiana backwater lakes by rotenone with information on minimum available size and abundance. [Species considered to be game fish are marked by an asterisk (*) and those considered commercial fish by a double asterisk (**).]

Common name	Scientific name	Minimum available size (total length or pounds)	Number of lakes from which taken	Pounds per acre		Percent of total weight	
				Mean for all lakes	Range	Mean for all lakes	Range
Non-Predaceous Fishes.....			7	230.4	74.4–539.5	55.7	25.7–82.9
*Bluegill sunfish.....	<i>Lepomis macrochirus</i>	5 inches	7	32.7	4.5– 52.2	8.8	1.2–20.6
*Redear sunfish.....	<i>Lepomis microlophus</i>	5 inches	7	8.5	0.1– 30.9	1.6	†0.0– 4.8
*Longear sunfish.....	<i>Lepomis megalotis</i>	5 inches	5	0.9	0.0– 5.9	0.3	0.0– 1.8
*Warmouth sunfish.....	<i>Chaenobryttus coronarius</i>	5 inches	7	13.4	0.6– 55.0	3.9	0.1–10.5
*Spotted sunfish.....	<i>Lepomis punctatus</i>	5 inches	6	4.0	0.0– 15.3	1.0	0.0– 3.5
*Orangespotted sunfish.....	<i>Lepomis humilis</i>	5 inches	1	0.3	0.0– 2.0	0.1	0.0– 0.4
*Green sunfish.....	<i>Lepomis cyanellus</i>	5 inches	3	†0.0	0.0– 0.2	†0.0	0.0– 0.1
Gizzard shad.....	<i>Dorosma cepedianum</i>		6	119.0	0.0–408.5	24.5	0.0–62.8
Threadfin shad.....	<i>Signalosa petenensis</i>		2	1.9	0.0– 11.8	0.4	0.0– 2.2
Skipjack herring.....	<i>Alosa chrysochloris</i>		3	0.2	0.0– 0.6	†0.0	0.0– 0.2
**Fresh-water drum.....	<i>Aplodinotus grunniens</i>	12 inches	6	19.1	0.0– 73.3	4.6	0.0–13.7
**Buffalo fishes.....	<i>Ictiobus cyprinellus</i> , <i>I. niger</i> and <i>I. bubalus</i>	16 inches	5	16.0	0.0– 40.0	4.5	0.0– 9.3
**Suckers.....	Mostly <i>Erimyzon succetta</i> and <i>Minytrema melanops</i>	None	4	3.3	0.0– 9.6	0.8	0.0– 1.8
**Yellow bullhead.....	<i>Ictalurus natalis</i>	None	4	1.4	0.0– 5.0	0.5	0.0– 2.3
**Black bullhead.....	<i>Ictalurus melas</i>	None	2	0.4	0.0– 1.5	0.2	0.0– 0.8
American eel.....	<i>Anguilla rostrata</i>		3	4.2	0.0– 27.5	1.3	0.0– 8.2
**Paddlefish.....	<i>Polyodon spathula</i>	15 pounds	1	1.3	0.0– 9.4	2.7	0.0–18.7
Striped mullet.....	<i>Mugil cephalus</i>		4	1.0	0.0– 5.0	0.3	0.0– 1.0
**Carp.....	<i>Cyprinus carpio</i>	None	1	0.1	0.0– 0.6	†0.0	0.0– 0.1
Other fishes.....	Mostly minnows (Cyprinidae) and other small fishes.....		3	0.4	0.0– 1.9	0.1	0.0– 0.4
Predaceous Fishes.....			7	166.7	67.4–388.6	44.3	17.1–74.3
*Largemouth bass.....	<i>Micropterus salmoides</i>	10 inches	7	23.7	6.8– 38.1	6.1	1.8– 9.8
*Spotted bass.....	<i>Micropterus punctulatus</i>	10 inches	1	0.3	0.0– 1.9	0.1	0.0– 0.6
*White crappie.....	<i>Pomoxis annularis</i>	7 inches	3	2.2	0.0– 8.4	0.9	0.0– 4.7
*Black crappie.....	<i>Pomoxis nigromaculatus</i>	7 inches	7	13.8	0.7– 50.3	3.1	0.4– 7.7
*Yellow bass.....	<i>Morone interrupta</i>	7 inches	2	1.4	0.0– 7.9	0.3	0.0– 1.5
*White bass.....	<i>Roccus chrysops</i>	7 inches	2	0.2	0.0– 1.0	†0.0	0.0– 0.3
*Chain pickerel.....	<i>Esox niger</i>	10 inches	1	†0.0	0.0– 0.2	†0.0	0.0– 0.0
*Longnose gar.....	<i>Lepisosteus osseus</i>	None	2	0.3	0.0– 1.9	†0.0	0.0– 0.3
**Shortnose gar.....	<i>Lepisosteus platostomus</i>	None	3	2.6	0.0– 14.0	0.6	0.0– 3.8
**Spotted gar.....	<i>Lepisosteus productus</i>	None	7	69.3	1.1–202.9	18.1	0.2–55.0
**Alligator gar.....	<i>Lepisosteus spatula</i>	None	4	10.6	0.0– 57.0	2.5	0.0–10.9
**Channel catfish.....	<i>Ictalurus punctatus</i>	14 inches	5	14.7	0.0– 50.1	5.1	0.0–19.6
**Blue catfish.....	<i>Ictalurus furcatus</i>	14 inches	4	4.7	0.0– 14.2	1.2	0.0– 3.7
**Flathead catfish.....	<i>Pylodictis olivaris</i>	14 inches	2	3.5	0.0– 19.5	1.3	0.0– 5.8
**Bowfin.....	<i>Amia calva</i>	None	5	19.7	0.0– 95.5	5.0	0.0–18.3

† Less than 0.05

cial fish and their minimum available sizes are shown in Table 2.

FACTORS AFFECTING ACCURACY OF RESULTS

Data obtained from rotenone poisoning or, for that matter, data obtained from samples taken with any type of gear, are more or less selective. Rotenone sampling is probably less selective than other methods. The main inaccuracy associated with this method is that varying percentages of fish occurring in the sampling areas are recovered (Lambou and Stern, 1958). However, all samples were taken in a similar manner and it is believed that the ratio of non-recovered fish to recovered fish was of

approximately the same magnitude for each sampling area. If this assumption is correct, the rotenone sampling data should furnish an unbiased index to the species composition and the abundance of fish in the backwater lakes. The method of taking rotenone samples in Louisiana and the factors affecting the results are more fully discussed by Lambou and Stern (1958).

Some species of fish—buffalo fishes, white bass, catfishes—are highly migratory in the backwater habitats. These fishes are often very abundant in the lakes during periods of high water and while the flood waters are receding. Evidently during periods of low water many of them move back into the river channels

Very little is known relative to the movement of these fishes in Louisiana backwater habitats. Fish sampling was confined to periods of low water; and therefore, the results are not indicative of the abundance of the migratory fishes.

FISH POPULATIONS OCCURRING IN BACKWATER LAKES

Standing crops of fish of all kinds

Standing crops of fish (pounds of fish per acre) occurring in the backwater lakes were high (Tables 2 and 3)—on the average much higher than standing crops of fish occurring in other types of habitat in Louisiana^{1, 2, 3, 4}. An average of 397 pounds of fish per acre was recovered from the lakes and the standing crops ranged from 142 for Colyell Bay to 651 for Spring Bayou Backwater Area.

An average of 230 pounds of non-predaceous fish per acre was recovered from the

lakes comprising 56 percent of the standing crops. The range was 74 to 540 pounds per acre comprising from 26 to 83 percent of standing crops in the various lakes. Gizzard shad, bluegill sunfish, fresh-water drum, buffalo fishes and warmouth sunfish were the principal non-predaceous fishes occurring in the lakes comprising, on the average, 25, 9, 5, 5 and 4 percent of the standing crops respectively.

¹ Lambou, Victor W. 1955. Annual and quarterly progress report. Project F1-R, June 1, 1954-May 31, 1955, mimeo.

² Lambou, Victor W., and Herbert Stern, Jr. 1958. Preliminary report on fish populations occurring in Louisiana backwater lakes, mimeo.

³ Lambou, Victor W., and Herbert Stern, Jr. 1958. Preliminary report on fish populations occurring in Louisiana impoundments, mimeo.

⁴ Lambou, Victor W., and Herbert Stern, Jr. 1958. Preliminary report on fish populations occurring in Mississippi River oxbow lakes in Louisiana, mimeo.

TABLE 3.—*Standing crops of fish, as determined by use of rotenone, in seven Louisiana backwater lakes and structure of populations as percentages of predaceous, non-predaceous, game and commercial fishes. [Available fishes are those as large or larger than the minimum accepted sizes shown in Table 2.]*

Lake	Standing crop pounds per acre	Percent of total weight						Principal species—those making up more than 3 percent of total weight
		Non-predaceous	Predaceous	Game fish		Commercial fish		
				Total	Available	Total	Available	
Spring Bayou Backwater Area	650.9	82.9	17.1	26.1	24.0	11.0	7.6	Gizzard shad, black crappie, bluegill sunfish, buffalo fishes, largemouth bass, redear sunfish
Old River	533.8	78.6	21.4	19.8	16.8	28.4	14.5	Gizzard shad, fresh-water drum, channel catfish, largemouth bass, bluegill sunfish, redear sunfish
Bayou Fourtableau Pitts	227.8	63.1	36.9	37.2	23.1	22.1	22.1	Gizzard shad, bluegill sunfish, bowfin, largemouth bass, black crappie, alligator gar, spotted gar
Bayou Fourtableau	369.1	34.2	65.8	4.2	3.1	76.3	68.8	Spotted gar, gizzard shad, buffalo fishes, fresh-water drum, shortnose gar
Colyell Bay	141.8	52.5	47.5	23.0	19.3	74.7	65.1	Channel catfish, paddlefish, spotted gar, buffalo fishes, warmouth sunfish, fresh-water drum, largemouth bass, white crappie, flathead catfish, bluegill sunfish
Pearl River Backwater	333.8	52.6	47.4	40.6	27.7	50.6	47.5	Spotted gar, bluegill sunfish, largemouth bass, American eel, buffalo fishes, fresh-water drum, warmouth sunfish, flathead catfish, channel catfish, blue catfish, spotted sunfish
Wabloon Bayou	522.7	25.7	74.3	31.4	21.9	67.7	67.3	Spotted gar, bowfin, alligator gar, warmouth sunfish, bluegill sunfish, largemouth bass, black crappie
All lakes	397.1	55.7	44.3	26.0	19.4	47.3	41.9	Gizzard shad, spotted gar, bluegill sunfish, largemouth bass, freshwater drum, channel catfish, bowfin, buffalo fishes, warmouth sunfish, black crappie

An average of 167 pounds of predaceous fish per acre was recovered from the lakes comprising 44 percent of the standing crops. The range was 67 to 389 pounds per acre comprising from 17 to 74 percent of the standing crops in the various lakes. Spotted gar, largemouth bass, channel catfish, bowfin and black crappie were the principal predaceous fishes occurring in the lakes comprising on the average 18, 6, 5, 5, and 3 percent of the standing crops respectively.

Standing crops of game fish were high with an average of 103 pounds per acre and ranging from 16 to 180 pounds per acre for the various lakes. Game fish comprised an average of 26 percent of the standing crops, ranging from 4 to 41 percent for the various lakes.

An average of 169 pounds of commercial fish per acre was recovered from the lakes ranging from 51 to 354 pounds per acre. Commercial fish comprised an average of 47 percent of the standing crop ranging from 11 to 76 percent. An average of 148 pounds of available commercial fish per acre was recovered from the lakes ranging from 49 to 352 pounds per acre. Available commercial fish comprised an average of 42 percent of the standing crop ranging from 8 to 69 percent.

Standing crops of available game fish

Standing crops of available game fish were high in the lakes with an average of 78 pounds of available game fish per acre, ranging from 12 to 156 pounds per acre (Table 4). Available game fish made up 19 percent of the total standing crops of fish. Available size bluegill sunfish, largemouth bass, black crappie, warmouth sunfish and redear sunfish were

abundant with standing crops of 24, 18, 11 and 8 pounds per acre respectively. These species made up approximately 6, 5, 3, 3 and 1 percent of the total standing crops respectively.

Approximately 76 percent of the total poundage of game fish consisted of available size fish (Table 4). A larger percent of the standing crops of game fish consisted of available size fish in the backwater lakes than in other types of habitat in Louisiana^{1, 2, 3, 4}. The percent of the total poundage of game fish of available size ranged from 62 to 92. Approximately 70 percent of the total poundage of bluegill sunfish, 81 percent of redear sunfish, 79 percent of warmouth sunfish, 76 percent of largemouth bass and 72 percent of black crappie were of available size.

Concentrations of fish

Fairly large concentrations of fish occur in relatively small areas in some of the backwater lakes. A total of 974 pounds of fish was recovered from the Spring Bayou Backwater Area in a single 1 acre sampling area (Table 5). Approximately 475 pounds of game fish, which 446 pounds were available game fish were recovered from this sampling area.

PREDATOR-PREY RELATIONSHIPS

An average of 1.9 pounds of non-predaceous fish per pound of predaceous fish was recovered from the backwater lakes (Table 6). The values ranged from 0.4 to 4.8 for the various lakes. These values are lower than those found in other types of habitat in Louisiana^{2, 3, 4}.

TABLE 4.—*Standing crops of available fish for the principal game fishes as determined by use of rotenone in seven Louisiana backwater lakes with information on percentage of total standing crop of the various game fishes which were of available size.*

Kind of fish	Available game fish				Percent of the total standing crops (weight) of the various game fishes which were of available size	
	Pounds per acre		Percent of total standing crop (weight)		Mean for all lakes	Range
	Mean for all lakes	Range	Mean for all lakes	Range		
Bluegill sunfish.....	23.9	2.4- 36.8	6.2	0.7-12.5	70.0	53.3- 83.0
Redear sunfish.....	8.2	*0.0- 30.3	1.6	*0.0- 4.7	80.5	*0.0-100.0
Warmouth sunfish.....	11.1	0.5- 43.9	3.3	0.1- 8.4	78.7	25.0- 96.7
Largemouth bass.....	18.0	6.2- 33.2	4.5	1.7- 7.8	76.1	48.3- 94.4
Black crappie.....	11.7	0.7- 49.2	2.6	0.2- 7.6	71.8	39.3-100.0
Total game fish.....	77.7	11.5-156.2	19.4	3.1-27.7	76.3	62.0- 91.9
Predaceous game fish.....	33.0	8.4- 89.4	8.0	2.3-13.7	77.3	56.1- 96.1
Total sunfish.....	44.7	3.1- 87.6	11.4	0.8-18.3	73.3	53.5- 87.9
Total crappie.....	13.5	0.8- 57.1	3.2	0.2- 8.8	68.3	39.3- 97.1

*None of the fish were available size or less than 0.05.

TABLE 5. — *Summary of a one acre rotenone sample of the fish population occurring in the Spring Bayou Backwater Area.*

	Pounds per acre	Percent- age of total pounds	Pounds per acre available game fish
NON-PREDACEOUS			
FISH	662.5	68.0	—
Bluegill sunfish	104.8	10.8	85.2
Redear sunfish	83.2	8.5	81.3
Warmouth sunfish	8.5	0.9	8.1
Gizzard shad	429.3	44.1	—
Buffalo fishes	36.7	3.8	—
PREDACEOUS FISH			
Largemouth bass	311.7	32.0	—
White crappie	83.2	8.5	79.0
Black crappie	19.7	2.0	19.3
Yellow bass	173.8	17.8	171.5
Chain pickerel	0.9	0.1	0.9
Shortnose gar	0.8	0.1	0.8
Spotted gar	7.3	0.7	—
Blue catfish	2.6	0.3	—
	23.4	2.4	—
TOTAL	974.2	—	—
Game fish	474.9	48.7	—
Available game fish	446.1	45.8	446.1
Commercial fish	51.3	5.4	—
Available commercial fish	48.3	5.0	—

The determination of the pounds of non-predaceous fish per pound of predaceous fish is of value; however, this ratio does not show the weight of forage fish these predators can utilize for food. In order to demonstrate this relationship, the following values must be determined: (1) the total weight of predaceous fish of a size large enough to feed mainly on other fish or other forage animals (large crustaceans) and (2) the total weight of fish or other forage animals of a size small enough to be utilized for forage by the predators. Wingle (1950) calculated a Y/C ratio where Y equals the total weight of those individuals in the forage group that are small enough to be eaten by the average size adult in the carnivorous group of fish, and where C equals the total weight of the carnivorous fish. Sufficient information to allow the determination of exactly what size forage fish could be utilized

by the predators in the populations sampled was not available. These predator-prey relationships are complex, especially in the case of fish populations containing many different kinds of fish. Some predators may utilize different size forage than others. Also, because a fish is of a size small enough to be utilized as forage doesn't necessarily make that fish available for forage. Some forage species may be easier to capture than others; therefore, it may take a larger population of a certain kind of forage fish than another kind to support an equal weight of predators. Some forage species may frequent habitats in the lake that are not inhabited by the predators. For example: can largemouth bass utilize threadfin shad which inhabit open water as readily as sunfish which normally don't inhabit open water? However, on occasion, largemouth bass in some Louisiana waters school and feed on threadfin shad. Even though these predator-prey relationships are complex and hard to determine, approximations of their values are useful in understanding the dynamics of fish populations.

In order to make approximations of the predator-prey relationships the following ratio was calculated: the pounds of all fish under 5 inches per pound of predaceous fish over 5 inches in the population. All kinds of fish were included in the prey group because it is probable that small fish of the kind that are predaceous when of adult size can be utilized as forage. It seems probable that very few fish over 5 inches in length are utilized as forage by the large predators. This breakdown is arbitrary and undoubtedly does not express the true relationship. However, if the assumption that few fish over 5 inches in length are utilized as forage is correct, then the amount of forage fish available for the predators over 5 inches in length is the maximum amount

TABLE 6. — *Some predator-prey relationships in seven Louisiana backwater lakes.*

	Spring Bayou Backwater Area	Old River	Bayou Courtableau Pitts	Bayou Courtableau	Colyell Bay	Pearl River Backwater	Dubloon Bayou	Mean for all lakes
Pounds of non-predaceous fish per pound of predaceous fish	4.8	3.7	1.7	0.5	1.1	1.1	0.4	1.9
Pounds of total fish under 5 inches per pound of predaceous fish over 5 inches	0.2	—	0.3	0.3	0.1	0.2	0.1	0.2

possible and the calculation of the ratio is of value for comparative purposes and for determining relationships in the population. The amount of available forage other than fish was not included in the predator-prey ratio inasmuch as it is not possible to sample crayfish and other crustaceans with rotenone.

On the average, there was 0.2 of a pound of fish under 5 inches per pound of predaceous fish over 5 inches in the backwater lakes (Table 6). Swingle (1950) concluded that Y/C ratio values in the range of 1.0 to 3.0 were the most desirable in order to have the proper balance in ponds. It seems improbable that predaceous fish in the backwater lakes could support themselves on considerably less available forage (by weight) than they themselves make up in the population. The values were low for all lakes sampled ranging from 0.1 to 0.3.

Swingle (1950) describes balanced fish populations as follows: "The inter-relationships in fish populations are satisfactory if the populations yield, year after year, crops of harvestable fish that are satisfactory in amount when the basic fertilities of the bodies of water containing these populations are considered. Such populations are considered to be balanced populations and the species within such populations are in balance."

I do not believe that these populations are unbalanced in the sense Swingle (1950) defines balance. From a sport fishery standpoint, the fish populations occurring in the backwater lakes are very desirable. These lakes support an average of 103 pounds of game fish per acre of which 78 pounds are available game fish. From all indications, the quality of the sport fishing on the backwater lakes is excellent, and considering the lakes as a group, probably is much better than that on most other bodies of water in Louisiana. However, this is based on observations alone inasmuch as insufficient creel census data are available to accurately compare the quality of the sport fishery occurring on the different types of lakes.

It would seem that the fish populations occurring in the backwater lakes are of a different type than the balanced or unbalanced populations described by Swingle (1950). Predator-prey relationships in other types of habitat in Louisiana (impoundments, flood plain lakes which don't over-flow, etc.^{3, 4}) are more similar to those in the balanced or unbalanced populations described by Swingle (1950).

Some type of forage other than fish must be important in the diet of predaceous fish in the backwater areas. I believe swamp crayfish (*Procambarus clarki*) are important in the diet of large predators in these lakes. I have observed largemouth bass utilizing swamp crayfish extensively for forage in some backwater lakes and during certain times of the year swamp crayfish are extremely abundant—in fact so abundant that there exists in the backwater areas a large commercial fishery for swamp crayfish. Large crustaceans are important in the diet of largemouth bass in other types of habitat. Lambou⁵ found that blue crabs (*Callinectes sapidus*) were very important in the diet of largemouth bass and other predators in a Louisiana brackish water habitat.

Fish collected by poisoning are not very suitable for the determination of condition factors. However, based on gross examination the large predators occurring in the samples taken from the backwater lakes appeared to be in excellent condition and not suffering from malnutrition.

EFFECTS OF OVERFLOW ON THE FISH POPULATIONS

The flooding of large expanses of land during high water periods undoubtedly has much effect on the ecology of the backwater lakes. Wood (1951) discussed the effects of fluctuating water levels on the fisheries in impoundments. There is no reason to believe that phenomena described by Wood (1951) do not also apply to the backwater lakes.

Undoubtedly sediments deposited by the rivers have a fertilizing effect on the lakes. The sediments carried by the major rivers in Louisiana are rich in the basic elements essential to the subsistence of plant and animal life. The alluvial flood plains of the Mississippi, Red and Atchafalaya Rivers contain some of the most fertile farm lands in the Southeast. Farm lands outside of the flood plains in Louisiana are much less fertile.

According to Wood (1951) the alternate exposure and flooding of land is important in maintaining and increasing the productivity of

⁵ Lambou, Victor W. 1952. Food and Habitat of Game Fish in the Tide Water of Southeastern Louisiana. Thesis, Louisiana State University and Agricultural and Mechanical College.

large impoundments. Undoubtedly this same phenomenon is of importance in the backwater lakes.

The alternate exposure and flooding of land has important effects on fish populations. If the flooding occurs during the spawning season it seems to induce the reproduction of great numbers of young of some fishes—for example, largemouth bass.¹

The flooding should limit the intra-specific and inter-specific competition for food, space, and spawning territory. Young fish should have an extremely abundant source of food and thus their mortality rates should be reduced and growth rates increased. Food in the form of fish and swamp crayfish, should be plentiful for the large predators, allowing them to make rapid growth. The whole fish population should be rapidly expanding in numbers and weight.

Undoubtedly the above phenomenon largely determines the type of fish population present during low water periods. However, even during low water, the backwater lakes are able to support large fish populations and large numbers of game fish. This is indicated by: (1) the high poundage of fish recovered from the sampling areas during low water periods; (2) the apparent excellent condition of both predaceous and non-predaceous fish during these periods; (3) the adequate representation of all sizes of fish in the samples and (4) the high quality of the sport fishing during low water periods.

It might be expected that there would be high mortality of fish during low water periods and Wood (1951) states that such is the case in the backwater lakes in the lower Mississippi River Valley. Abnormally high mortality rates have not been shown to occur in the backwater lakes in Louisiana. Even if high mortality rates do occur, sufficient fish survive from year to year to maintain a population of game fish with adequate representation in the larger size groups.

CLASSIFICATION OF FISH POPULATIONS OCCURRING IN BACKWATER LAKES

Wood (1951) classified fresh water fish populations into three types: (1) crowded populations; (2) balanced populations; and (3) expanding populations. He describes expanding populations as follows: "In large impoundments there exists for a few years following initial filling, a type of fish population which almost invariably provides good fishing;

although it does not seem to fit any type previously described. In this type, balance between predator and prey may or may not prevail and the population may contain considerable numbers of rough fish; nevertheless, the population is composed of an assemblage of fishes rapidly expanding in numbers, average size, and total weight." Wood further states that, "Expanding fish populations are dynamic and, aside from being typical of new impoundments, characterize best the fish populations of natural lakes in the flood plain of the lower Mississippi River."

I believe that a distinction should be made in the expanding population type occurring in new impoundments and the type occurring in Louisiana backwater lakes. The expansion phase in new impoundments occurs throughout the growing season and over a span of several years. The phase where the population is rapidly expanding in the backwater lakes occurs only during part of the growing season but usually recurs to a greater or lesser extent each year. I believe these differences would have different effects on the fish populations. I would classify the populations occurring in the backwater lakes as fluctuating populations.

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Careers in Fisheries

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In the United States and Canada today, we have reached the highest peak in productivity per capita and consequently the highest average standard of living that the world has ever seen. Surpluses in food and in industrial goods have lulled many of us, both young and old, into a false sense of irresponsibility toward the future. We have come to feel that our main function in life is to sit in the shade and to consume and enjoy the good things that have been provided for us alone, of all the world, by our superior intelligence and boundless energy under the "American Way of Life." We tend to forget that much of our good fortune has resulted from the low population density, the large areas of arable land, and the bountiful natural resources of two exceptionally lucky young nations.

These causes of good fortune are in the process of change. In the United States, the population in 1900 was 75.9 millions; fifty years later, due to immigration plus natural increase, it was over 150 million. With increases in length of life, the population is now expected to double every 40 to 50 years. By the year 2000, we expect the population of the United States to reach 300 million, with possible further increase to 600 million by 2050.

Coupled with these increases in population density is the gradual decrease in the total acreage of arable land because of erosion and increased requirements for living space, roads, airports, impoundments for water supplies, and similar land usages. As a result, it is quite evident that each acre of land and each acre of water must produce more and more food during succeeding generations or the standard of living must gradually decline to a joyless minimum. It is also a fact established by history, that sustained production does not result without intelligent planning and research, and that proportionally greater effort must be expended if production must be continuously increased.

Today in Fisheries, as in other fields, we are attempting to conserve and improve a tremendously valuable renewal resource with insufficient and often inadequate personnel. We must compete on a national level, and often on the international level, for the young people who are to assume these responsibilities and carry on this work.

The problem of adequate personnel is increasingly difficult of solution, because of the increasing amounts of education and training needed in these positions. The fisherman, the hatcheryman, the management biologist, and the research biologist each must learn to use complicated tools and skills unknown to his predecessors of a generation ago. Usually, a college student, while unfamiliar with the various professions, must decide for which field he will prepare himself and what skills he will need.

This problem could be solved in part if, in industry and in the professions (including fisheries), part-time jobs as apprentices were generally made available to high school and college students. Such work would familiarize them with the various fields of specialization, and give them a goal towards which to work. It is the tragedy of many young people that there is nothing important for them to do, and they grow up ignorant or unconvinced that their best efforts are urgently needed in this world. Without this sense of being needed, they spend more energy in escaping than in obtaining the education they will so greatly need.

We, as a nation, now bemoan our sad plight in producing too much food. We blame the farmer, the fisherman, the administration, the research scientist, and the weather. It seldom occurs to us that this abundance of food is a blessing few civilizations have enjoyed and, except for certain circumstances, we might be blaming the farmer, the administration, or the scientist because we did not have *enough* to eat. Gradually and surely, the problem of agricultural surplus is being solved by human reproduction, not by legislation.

It is clear, however, that if coming generations are to have the privilege of having sur-

¹ Presidential Address at the 88th Annual Meeting of the American Fisheries Society at Philadelphia, Pennsylvania, September 8, 1958.

plus food—or even of having enough, planning and research on how to increase production on land and in water must be vigorously carried on during this present period of overabundance in preparation for the future. Research is never for today and much of the research of this generation benefits principally the next generation. Thus is paid our debt to preceding generations.

If we are to maintain a desirable standard of living, sufficient food, clothing and material things are not enough. Man must still have those facilities for relaxation, for meditation, and for recreating the imperturbable spirit so needed in modern civilization. Sport fishing is the chief outdoor recreation serving all of these purposes. Its adequate expansion will require intelligent planning and a great increase in basic research.

Similarly, the problems of maintaining adequate renewable and non-renewable resources in a fixed area, with a population increasing in density and with a civilization increasing in complexity, will require the best thought and efforts of each generation.

We can only say to our young people that we are handing on to them very complex problems—the solutions of which will require minds better trained than ours. We have improved transportation, thus making it urgent—necessary to develop the ability to get along

with other peoples. We have learned how to utilize large amounts of energy in industry, transportation, and all phases of modern life, thus making it necessary to develop new sources of energy. We have wasted renewable and non-renewable resources, thus making necessary strict conservation and the development of substitutes. We have left to them few new frontiers of space on earth, but have opened to them thousands of new frontiers in the industries, in the professions, and in the sciences.

The young people of this generation are confronted with the necessity of choosing for their life profession from a vastly greater number of fields of specialization than was available to any preceding generation.

In choosing their life work, we wish to remind these young people of the fisheries' profession. Remember that three-fourths of the world's surface is covered by water, that aquatic resources must be depended upon to provide increasing percentages of our food and recreation, that fisheries is a *young* profession, and that many of the undeveloped frontiers awaiting discovery by the adventuresome lie within the field of fisheries. For young people liking the outdoors and who feel a compelling urge to spend their lives in work important to the future of mankind, a career in fisheries will be rewarding.

A Survey of Technical Fishery Personnel¹

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ABSTRACT

A mail survey of fish conservation agencies indicated that in 1958, there are at least 1673 technical fishery personnel in United States and 232 in Canada. If classified according to major responsibility, 900 are in research, 354 in management, 249 in administration, 232 in survey and trouble-shooting, 138 in fish culture, and 32 in education. Lines between technical and non-technical personnel are difficult to draw, particularly in fish culture. State and provincial agencies hire 50.4 percent of the personnel, federal agencies 39.1 percent, colleges 8.9 percent and 1.6 percent were listed as privately employed. Over 91 percent of the personnel have college degrees and almost 44 percent have advanced degrees. Over half of those in management, survey, and research are under 35 years of age, attesting to the rapid growth of the field. Only 41 percent of those listed are members of the American Fisheries Society. About one-third of the personnel deal with marine fisheries and most of these are in research activities. Most biologists and managers hired by state conservation departments have broad responsibilities.

INTRODUCTION

In discussions of the professional status of the fishery biologist and of the need for professional standards, it became apparent that we knew very little about the numbers, geographical distribution and training of those now considered as fishery biologists. Therefore, a questionnaire was sent in April 1958 to each state conservation agency, each university and college giving fishery biology courses, the Soil Conservation Service, the U. S. Public Health Service, the U. S. Corps of Engineers, each Canadian provincial agency, the Fisheries Research Board of Canada, the Canadian Wildlife Service, various treaty and interstate commissions, and to a few individuals. The Fish and Wildlife Service mailed the questionnaires to the various regional offices and laboratories. The author wishes to express his appreciation for the almost 100 percent cooperation received in completing these questionnaires.²

The questionnaire asked that all fishery personnel (at least one-third of their time must be

spent on fishery problems) with technical training or experience and technical responsibility be listed. For each individual, the age, educational background, and a breakdown of his job responsibilities was requested. Data were included on 1905 individuals (Table 1).

TABLE 1.—Numbers of fishery personnel in various job categories.

	Number in each category	Percentages having duties in fisheries other than the designated category	Percentage having duties other than fisheries
Fish Culture	138	77.5	0.7
Management	354	92.1	17.2
Survey and trouble-shooting	232	70.7	9.4
Research	900	51.3	6.4
Education	32	87.5	68.7
Administration	249	70.7	11.6
Total	1905	66.3	10.1

PROBLEMS OF CLASSIFICATION

A major problem in a survey such as this is that of determining where the lines should be drawn in defining a fishery biologist or a fishery worker with technical training or responsibility. In the questionnaire, the definitions were left in general terms so that each respondent could use his judgment as to where the lines should be drawn. In going over the results, I was pleased with the general agreement in definitions by the various agencies. There were some obvious differences, largely

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²A mimeographed list of those returning the questionnaires was distributed at the Philadelphia meeting of the American Fisheries Society and will be sent by the author to those requesting it.

to whether fish hatchery personnel should be included. Some listed none of the fish culture personnel, some listed only those hatchery supervisors with technical education, and some listed all hatchery supervisors. Fish culture personnel other than the supervisors, and a few research workers were not listed by any respondent.

The questionnaire asked that the duties or responsibilities of each person be designated, on a percentage basis, as administration, education, research, survey and trouble shooting, management, and fish culture. Such designations are obviously arbitrary and the same job might, for example, be called research by one person and survey or trouble-shooting by another, but it is believed that most of the classifications were quite comparable. About two-thirds of the persons were listed as having responsibilities in more than one category (Table 1). In the summaries given in this paper these persons were classified in the category where the greatest part of their responsibility lay. Where the amounts of responsibility in two or more categories were equal, the person was listed as in the first category as in Table 1.

About 10 percent of the listed personnel had professional responsibilities other than in fisheries. These other responsibilities were largely with respect to conservation and management of birds, mammals and other wildlife. Only persons with at least one-third time in fisheries were listed.

Almost half of the personnel were listed as having research as their primary responsibility, and this group had the smallest percentage of other duties in the fishery field. The small number listing education as their major responsibility may be surprising until it is realized that many in educational institutions listed research as their major responsibility in the fishery field.

EMPLOYERS

State and provincial agencies hire 50.4 percent of the personnel listed in this survey (Table 2). Federal agencies, including commissions set up by treaties, hire 38.5 percent. Computing those hired by colleges, graduate students and graduate research assistants were eliminated from the survey. The numbers in private employment are probably underestimated in this survey since the questionnaires were sent mostly to governmental and educational agencies. Each person was asked to list his fishery personnel in his state or region

TABLE 2.—*Fishery personnel in various categories listed according to type of employer.*

	Federal agencies	State and provincial agencies	Colleges	Non-governmental employment
Fish culture	79	47	1	11
Management	99	245	0	10
Survey and trouble shooting	63	167	0	2
Research	418	337	140	5
Education	3	7	21	1
Administration	82	158	7	2
Totals	744	961	169	31

who might be missed. It is known that in several regions there are many other persons operating private fish hatcheries. It is believed, however, that few of these operators are technically trained. Undoubtedly more are technically trained than are included in the present survey.

ACADEMIC TRAINING

Over 91 percent of those listed in this survey have a college degree and almost 44 percent have advanced degrees (Table 3). Since the management and the survey and trouble-shooting categories showed such similar distributions with respect to educational training and age, these categories were combined in this and some of the other tabulations. Most of those without college degrees were over 40 years old and had considerable experience in the fishery field.

TABLE 3.—*Educational training of fishery biologists classified according to major activity¹.*

Major Activity	Numbers with the following as highest degree	High School	Bachelor's	Master's	Doctorate
Fish culture	77	40	17	1	
Management and survey	51	364	154	11	
Research	21	382	282	214	
Education	2	7	4	48	
Administration	17	100	85	48	
Totals	168	893	542	293	

¹ Information on educational training was not available on 9 persons.

AGE

The fact that fishery conservation is a new field is indicated by the age distribution of the personnel (Table 4). Over half of those in management, survey, trouble-shooting, and research are under 35 years old. Those in fish culture average somewhat older, as this aspect of fish conservation has a longer history. Furthermore, as has already been pointed out, only

TABLE 4.—*Age distribution of personnel in various branches of fishery conservation.*

	Number	Average	Cumulative percentage in each age group									
			20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69
Fish culture . . .	133	45	2.3	5.3	18.0	32.3	48.9	66.9	83.5	94.0	98.5	100.0
Management and survey . . .	563	35	3.9	25.9	55.8	79.7	90.6	95.5	97.5	98.9	99.6	100.0
Research	882	35	3.7	24.9	54.9	78.2	88.5	94.3	96.9	98.3	99.2	100.0
Education	32	40	9.4	12.5	25.0	50.0	71.9	81.3	90.6	100.0	—	—
Administration . .	249	43	—	2.0	12.9	40.2	60.6	81.1	91.6	97.2	99.6	100.0
Combined	1859	37	3.3	20.5	46.4	69.8	82.3	90.7	95.3	98.1	99.4	100.0

hatchery supervisors and others with considerable experience were listed by most of the respondents. Those in education and in administration are also a little older, as might be expected from the training and experience usually required in these fields. Obviously, few fishery biologists are near retirement age and therefore openings in the field are coming largely through expansion.

MEMBERSHIP IN AMERICAN FISHERIES SOCIETY

A comparison of the listed fishery personnel with the November 1956 membership list of the American Fisheries Society indicated that only 41.2 percent of the technical fishery personnel were members (Table 5). The freshwater biologists are better represented in the Society than are those working on marine fisheries. This may be an indication of a failure of the Society to meet adequately the needs of the marine biologist.

TABLE 5.—*Percentages of fishery personnel who are members of the American Fisheries Society.*

	Fish cul- ture	Mane- ment and survey	Re- search	Educa- tion	Ad- minis- tration	Total
Freshwater	21.5	41.4	54.3	44.4	67.4	46.5
Colleges	.....	.....	55.0	66.7	85.7	59.1
Marine	.....	23.3	24.9	100.0	50.0	27.2
Combined	21.5	37.9	39.1	62.5	64.3	41.2

GEOGRAPHICAL DISTRIBUTION

The regional designations of the U. S. Fish and Wildlife Service were used in tabulating the geographical distribution of fishery personnel (Table 6). A higher percentage of the biologists listed from Canada have doctorate and master's degrees than in any area of the United States. Southeastern United States has about the same percentage with at least a master's degree as Canada but has a lower percentage with the doctorate. The Pacific Coast

states, with the highest number of fishery personnel have the lowest percentage with advanced degrees.

COMPARISON OF MARINE AND FRESHWATER FISHERY PERSONNEL

About one-third of the listed fishery personnel deal with marine fisheries and the other two-thirds with freshwaters (Table 7). Most of those in marine area deal with commercial fisheries while those on inland waters are largely concerned with sport fisheries. A high percentage of those in marine fisheries were listed as being primarily in research, whereas in the freshwater fisheries almost half of the personnel were listed as having management, survey, or trouble-shooting as their major responsibility. Practically all management on ocean fisheries must be accomplished through control of the catch, which requires many persons in research and few in management. On inland waters much more is done through habitat control and therefore there are greater demands in the management and survey aspects of fish conservation. Within the various categories, the academic backgrounds seem to be quite similar in the marine and freshwater fields. A high percentage of those in administration in the marine fisheries have PhD degrees than those in administration in freshwater fields, where administrators may come from the management rather than the research ranks.

JOB SPECIFICATIONS

Several of the state conservation departments listed the payroll designation of each person. A comparison of the job breakdown, academic background, and average age showed little difference between persons in comparable designations in large departments (*i.e.* those listing more than 30 technical fishery persons) and in smaller departments. The larger department

ometimes had more promotional grades but comparisons of those in the first two or three grades and of those in the highest grades indicated little difference between small and large departments.

Although those designated as biologists usually had major responsibility for research, most of them had other responsibilities as well (table 8). The fish and game assistant classification should probably be considered at the professional level. The description of their duties indicated that they were primarily field assistants in tagging fish. The other categories showed a general increase in age, academic training, and membership in the American Fisheries Society, with increase in grade as would be expected. The low average age of those in these positions is significant, however, and is undoubtedly a result of the rapid growth of the field.

Persons in fishery management (Table 9) averaged somewhat older than those listed as biologists. In the expansion of this aspect of fish conservation, there have been more opportunities for persons having field experience but lacking specialized academic training. A significant percentage of those in fishery management, however, do have at least a master's degree.

DISCUSSION

It might have been wiser to have given this survey a wider base and to have collected comparable data on all persons working in fish conservation. The present survey excluded most people working in fish propagation, the men who pull the seines in rough fish control, conservation officers who enforce the laws and interpret fish conservation to much of the public, area managers responsible for development and maintenance of fishing sites, the office staff that handle essential business matters and

TABLE 7.—Some comparisons of fishery personnel in marine and freshwater fisheries

	Marine				Freshwater			
	Number	Percentage with at least			Number	Percentage with at least		
		BS	MS	PhD		BS	MS	PhD
Fish culture.....	5	80	40	0	133	39	10	1
Management and survey.....	69	87	16	5	528	91	31	1
Research.....	474	97	46	19	426	98	59	18
Education.....	5				27			
Administration...	52	96	53	34	186	92	50	12
	605				1300			

TABLE 6.—Numbers of fishery personnel in various regions of United States and Canada.

Region	Fish Culture	Management and Survey	Research	Education and Administration	Total	Highest academic degree		
						PhD	MS	BS
Washington, Oregon, California, Nevada, Idaho, Montana	41	134	256	54	483	45	111	283
Wyoming, Utah, Colorado, Arizona, New Mexico, Kansas, Oklahoma, Texas	12	77	46	16	151	20	47	73
North Dakota, South Dakota, Nebraska, Minnesota, Wisconsin, Michigan, Missouri, Iowa, Illinois, Indiana, Ohio	47	136	143	75	401	59	108	174
Arkansas, Louisiana, Mississippi, Alabama, Georgia, Florida, North Carolina, South Carolina, Tennessee, Kentucky, Virginia, Maryland, D. C., Maine, New Hampshire, Vermont, Connecticut, Rhode Island, Massachusetts, New York, New Jersey, Pennsylvania, Delaware, West Virginia	19	83	172	48	323	53	133	117
Alaska and Hawaii	8	55	102	46	211	38	56	105
Alaska	2	35	55	10	102	12	19	60
Western Canada (Manitoba, west)	6	34	47	11	98	25	33	34
Eastern Canada (Ontario, east)	3	32	79	20	134	41	35	47
Totals	138	586	900	281	1903	293	542	893

many others upon whom the conservation of our fishery resources depends. In any event some lines would have to be drawn across broad areas where inclusion or exclusion from the survey would involve a subjective decision. Many of these other persons have responsibility for the conservation not only of fishery but also of other wildlife resources and the degree of their involvement in the fishery field may not

be clearly definable. In general, this survey indicates that there is a rather high degree of unanimity in circumscribing or defining the technical fishery worker. More specific standards and specifications would undoubtedly have to be developed before a roster of fishery biologists or some other register of professional fishery personnel can become a reality.

TABLE 8.—*Job profiles of some positions in fishery biology as listed by state departments.¹*

	Num- ber	Admin- stra- tion	Edu- cation	Re- search	Survey and trouble- shoot- ing	Man- age- ment	Fish cul- ture	Mem- ber	HS	BS	MS	PhD	A
Fish and game assistant	7	43	0	100 100	14	0	0	0	100	0	0	0	
Biologist trainee	25	28	8	92 80	48 8	44 4	4	12	28	68	8	0	
Biologist I	89	25	32	74 49	66 25	43 9	2	28	3	74	21	1	
Biologist II	90	43	47	91 50	70 11	58 9	1	46	0	50	42	8	
Biologist III	55	60 7	42	80 40	73 15	51 7	9	38	2	57	31	10	
Biologist IV	7	86 86	28	71 14	71	57	0	29	0	72	14	14	
District biologist	53	49	57	83 4	98 17	100 25	27	43	6	65	29	0	
Regional biologist	15	87 7	100	73	87 13	100 13	13	67	0	60	40	0	
Chief fishery biologist	29	86 69	38	66 14	34 7	79	14	72	3	31	44	24	
D-J assistant leader	17	29	41	100 6	65 71	47	0	18	0	94	6	0	
D-J leader	29	52	34	100 93	38 4	21	4	55	0	45	48	7	
D-J coordinator	9	100 78	22	67 11	22	33	11	89	0	56	44	0	

¹ The figures under the job categories (Administration, Education, etc.) indicate the percentage of those which indicated that they spent some time on each of these activities. The lower figures below some of these figures indicate the percentage that reported over one-half of their time was spent on the activity. Under Member is indicated the percentage who are members of the American Fisheries Society. The percentages with the designated degree as their achieved level of formal education are indicated as high school, BS, MS, or PhD. The age column gives the average age of the personnel.

TABLE 9.—*Job profiles of some positions in fishery management as listed by state departments.¹*

	Num- ber	Admin- stra- tion	Edu- cation	Re- search	Survey and trouble- shoot- ing	Man- age- ment	Fish cul- ture	Mem- ber	HS	BS	MS	PhD	A
Fish manager I	25	12 8	28	8	64 20	92 68	24	16	48	40	12	0	4
Fish manager II	10	20	80	90	90 80	100 20	0	30	0	70	30	0	
District fish manager	49	100 31	100 8	51	100	100	37	65	8	73	14	4	3
Regional fish manager	18	100 100	72	33	89	89	67	33	22	44	34	0	4
Fish culture superintendent	8	75 50	25	25	25	13	63 37	57	50	25	25	0	4
Assistant chief	20	100 90	20	45	45	35	5 5	60	5	40	55	0	4
Chief, or superintendent	41	93 80	46	32	32	39 7	26	88	10	35	39	16	4

¹ See explanation on Table 8.

Relative Toxicity of Ten Chlorinated Hydrocarbon Insecticides to Four Species of Fish

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ABSTRACT

Bioassays were conducted on ten commonly used chlorinated hydrocarbon insecticides to determine their comparative toxicity to fish. All of the compounds except BHC were extremely toxic to fish with 96 hour TL_m values generally below 0.1 p.p.m. Endrin was the most toxic with TL_m values ranging as low as 0.6 p.p.b. Bluegills were the most sensitive fish, followed by fathead minnows, goldfish and guppies, respectively. Changes in water quality characteristics (pH, alkalinity, hardness) had no apparent effect on toxicity. Acetone solutions and emulsible concentrates were equally toxic and were the most toxic formulations. All of the chlorinated hydrocarbon insecticides except BHC were more toxic to fathead minnows than the most toxic of the organic phosphorus insecticides. Additional areas of needed research are suggested.

INTRODUCTION

Since discovery of the insecticidal properties of DDT in 1939, there has been a tremendous increase in the development and use of organic insecticides. At present both chlorinated hydrocarbon and organic phosphorus compounds are widely used for insect control and have largely replaced arsenicals and other compounds for most insecticidal purposes.

The release and widespread public use of DDT following World War II caused some apprehension among conservationists as to its possible effects on fish and wildlife. Numerous studies (Erickson, 1947; Linduska and Surber, 1948; Hoffman and Surber, 1948, 1949; Hoffman and Linduska, 1949; Tarzwell, 1947, 1950) sought to determine the effects of large-scale applications of DDT on fish and wildlife which resulted in some suggested safeguards for its use. However, many new and more toxic so-called "superinsecticides" have been developed, marketed, and extensively used without proper testing as to their possible effects on fish and wildlife. Large-scale application of some of these materials has reportedly caused considerable damage. Much of the available information on research and reported damage is ably summarized by Todd and Genelly (1956). Among recent reports are the destruction of the fish population in a Florida marsh area by the application of one pound of dieldrin per acre for control of marsh mosquitos (Harrington and Bidling-

mayer, 1958) and some damage to fish and wildlife from applications of dieldrin and heptachlor for fire ant control in the South (Sport Fishing Institute, 1958).

Interest in insecticides from the standpoint of water pollution centers upon their effects on certain water uses, including such beneficial uses as those for domestic, agricultural and recreational purposes. Insecticides may enter surface or ground waters through direct application to water surfaces (e.g. mosquito control), accidental drift from aerial application or in runoff and seepage from treated land areas. The long-term residual toxicity of the chlorinated hydrocarbon insecticides gives them particular significance as possible water pollutants. Studies are now in progress to determine the effectiveness of conventional water treatment processes in the removal of some of these materials from drinking water supplies. Such treatment involves the removal of tastes and odors as well as toxicity.

The toxicity to fish and other aquatic life of some of the chlorinated hydrocarbon insecticides has been established in both laboratory and field studies (Surber, 1948; Surber and Hoffman, 1949; Lawrence, 1950; Doudoroff et al, 1953; Mayhew, 1955). In fact, one of these compounds, toxaphene, was found so toxic that it was suggested for use in fishery management to remove undesirable fish populations (Tarzwell, 1950).

The present study was undertaken to determine, by direct comparison, the relative toxicity of some widely used insecticides to several

common species of warm water fishes and to obtain information on the effects of certain water quality characteristics on their toxicity. The information would be highly important in the pollutional characterization of such materials and in establishing safeguards for their use.

Bioassays were made on ten chlorinated hydrocarbon insecticides now being used, or proposed for use in large scale insecticidal operations. Four species of fish and two dilution waters with widely different characteristics were used in the toxicity evaluations. Some studies were also made to determine the relative toxicity to fish of different formulations of the same compound.

CHLORINATED HYDROCARBON INSECTICIDES

For this comparative study, the insecticides were obtained from manufacturers in their purest available form. All samples were either technical grade or reference standard material. Because these compounds are practically insoluble in water, it was necessary to use an organic solvent to obtain proper distribution for the bioassay test solutions. Acetone was the selected solvent as it is relatively nontoxic to fish and readily miscible with water. A few samples of formulated insecticides were also obtained for comparison of their toxicity with that of the acetone solutions of the pure compounds. The formulations were distributed in the test aquaria in the form of water emulsions or suspensions.

Following is a description of the materials tested, including their chemical names, some of their more pertinent properties, and their composition. This information was obtained from the manufacturers, from Metcalf (1955) and from Technical Development Laboratories (1956).

Aldrin, technical

Chemical name — 1, 2, 3, 4, 10, 10-Hexachloro — 1, 4, 4a, 5, 8, 8a — hexahydro — 1, 4 — endo, exo — 5, 8 — dimethanonaphthalene, $C_{12}H_8Cl_6$.

Properties — Brown waxy solid, soluble in most organic solvents, insoluble in water.

Composition — 88.4 percent aldrin; 4.6 percent related compounds.

Dieldrin, technical

Chemical name — 1, 2, 3, 4, 10, 10-Hexachloro — 6, 7 — epoxy — 1, 4, 4a, 5, 6, 7, 8, 8a — octahydro — 1, 4 — endo, exo — 5, 8 — dimethanonaphthalene, $C_{12}H_8Cl_6O$.

Properties — Light tan flaky solid, moderately soluble in many organic solids but rather insoluble in most of the aliphatic petroleum solvents. Practically insoluble in water.

Composition — 90 percent dieldrin.

Endrin, technical

Chemical name — 1, 2, 3, 4, 10, 10 — Hexachloro — 6, 7 — epoxy — 1, 4, 4a, 5, 6, 7, 8, 8a — octahydro — 1, 4 — endo, endo — 5, 8 — dimethanonaphthalene, $C_{12}H_8Cl_6O$.

Properties — Light tan solid, moderately soluble in organic solvents, insoluble in water.

Composition — 91 percent endrin.

Endrin, emulsible concentrate

Properties — Dark brown liquid, readily emulsifies in water.

Specific gravity — 0.96.

Composition — 19.5 percent endrin, 73 percent petroleum hydrocarbons, 7.5 percent inert ingredients.

Endrin, wettable powder

Properties — Light tan powder, readily emulsifies in water.

Composition — 75 percent endrin; 25 percent inert ingredients.

Chlordane, reference standard

Chemical name — 1, 2, 4, 5, 6, 7, 8, 8 — Octachloro — 2, 3, 3a, 4, 7, 7a — hexahydro — 4, 7 — methanonaphthalene, $C_{10}H_6Cl_8$.

Properties — Dark brown viscous liquid. Soluble in most organic solvents but insoluble in water. Specific gravity — 1.5.

Composition — Pure chlordane.

Chlordane, emulsible concentrate

Properties — Dark brown liquid, readily emulsifies with water.

Specific gravity — 1.3.

Composition — 75 percent chlordane, 25 percent inert ingredients.

Heptachlor, technical

Chemical name — 1, 4, 5, 6, 7, 8, 8 — Heptachloro — 3a, 4, 7, 7a — tetrahydro — 4, 7 — endo methanonaphthalene, $C_{10}H_5Cl_7$.

Properties — Light tan, waxy solid, readily soluble in organic solvents and insoluble in water.

Composition — 72 percent heptachlor, 28 percent related compounds.

Toxaphene, reference standard

Chemical name — Octachlorocamphene — structure formula not yet determined, $C_{10}H_{16}Cl_8$.

Properties — Yellow, waxy solid, soluble in organic solvents but insoluble in water.

Composition — Highest purity containing 67-69 percent chlorine.

DDT, technical

Chemical name — 2, 2, bis — (*p*-Chlorophenyl) — 1, 1 — trichloroethane, $C_{14}H_9Cl_5$.

Properties — White powder, soluble in most organic solvents, but insoluble in water.

Composition — 76 percent *p*, *p'* isomer, 24 percent *o*, *p'* isomer.

DDT, reference standard

Properties — White powder.

Composition — 100 percent *p*, *p'* isomer.

Methoxychlor, reference standard, recrystallized

Chemical name — 2, 2 — bis (*p*-methoxyphenyl) — 1, 1, 1 — trichloroethane, $C_{16}H_{15}O_2Cl_3$.

Properties — White crystalline solid, soluble in most organic solvents and insoluble in water.

Composition — Pure *p*, *p'* isomer.

Lindane, reference standard

Chemical name—*Gamma*—1, 2, 3, 4, 5, 6—hexachlorocyclohexane. $C_6H_6Cl_6$.

Properties—White crystalline solid, soluble in most organic solvents but insoluble in water.

Composition—Pure *gamma* isomer.

BHC, technical

Chemical name—Benzene hexachloride. A mixture of isomeric 1, 2, 3, 4, 5, 6—hexachlorocyclohexanes, $C_6H_6Cl_6$.

Properties—White powder, soluble in a variety of organic solvents and practically insoluble in water.

Composition—15.5 percent *gamma* isomer.

BIOASSAY METHODS

Bioassays were conducted, essentially, according to the method recommended by the toxicity committee of the Federation of Sewage and Industrial Wastes Associations (Doudoroff *et al.*, 1951). Laboratory facilities and equipment were similar to those described by Henderson and Tarzwell (1957).

This method consists of preparing various concentrations of the test material in a selected dilution water, adding the test fish, and observing their reactions for a definite time. For use in plotting and interpreting results test solutions were prepared with concentrations in logarithmic series such as 10, 5.6, 3.2, 1.8, and 1.0 p.p.m.

As these chemicals were of unknown toxicity, small-scale exploratory tests were made to determine the approximate toxic range. Test solutions were prepared over a wide range of concentrations (e.g. 100, 10, 1.0, 0.1 p.p.m.). Two fish were added to two liters of each concentration in 6½-inch diameter, 1-gallon widemouth glass bottles. Observations for a short period (overnight) indicated test concentrations necessary for full-scale experiments.

In the full-scale tests, ten fish were used at each concentration. For all species except guppies, five fish were added to 10-liter duplicate samples in 5-gallon widemouth glass bottles, 10 inches in diameter. Tests with guppies were made in 1-gallon glass bottles, using five fish in 2 liters of duplicate samples. The intermediate tested concentrations were determined upon information obtained from the laboratory tests. For example, if fish were killed in concentrations of 10 p.p.m. and not at 1 p.p.m., intermediates were set up within this range (e.g. 10, 5.6, 3.2, 1.8 and 1.0 p.p.m. insecticide).

Two of the species of fish used in the bioassays, fathead minnows (*Pimephales promelas*) and bluegills (*Lepomis macrochirus*),

were wild native species raised in outdoor ponds at the State Fish Hatchery at Newtown, Ohio. The other two were so-called common household species, goldfish (*Carassius auratus*) and guppies (*Lebistes reticulatus*). Goldfish were obtained in uniform lots from a commercial fish farm and guppies were raised in our laboratories. Fathead minnows, bluegills, and goldfish were of similar size, ranging in length from 1½ to 2½ inches and in weight from 1 to 2 grams. Guppies were approximately six months old, ¾ to 1 inch long, and weighed from 0.1 to 0.2 grams. All of these species were easily maintained in the laboratory and were highly satisfactory for conducting bioassays.

Two dilution waters were used: (1) soft water prepared in the laboratory by mixing 95 parts of distilled, demineralized water and 5 parts of a natural spring water; (2) hard water, a natural limestone water obtained directly from springs. Before use, these waters were adjusted to the test temperature and aerated vigorously for about one hour to bring dissolved gases to near equilibrium with the atmosphere. At time of use, the average characteristics of these waters were as follows:

	Dissolved Oxygen p.p.m.	pH	Alkalinity p.p.m.	Hardness p.p.m.
(1) Soft Water	8.0	7.4	18	20
(2) Hard Water	8.0	8.2	360	400

Fresh preparations of the chlorinated hydrocarbon compounds or formulations, usually 0.01 or 0.001 percent in acetone or water, were made up and computed quantities added directly to the test aquaria. Fish were then added and their reactions observed during the test period.

All bioassays were conducted in a constant temperature room at 25°C, which would approximate summer temperatures of many natural waters.

This type of bioassay is designed so that artificial aeration or oxygenation is not normally required when using chemicals having little or no oxygen demand. Absorption of atmospheric oxygen by the exposed water surface is usually adequate for fish requirements during the test period. However, the addition of acetone apparently increases bio-oxidation, causing a slight oxygen depletion in some test solutions. When needed, pure oxygen was added in the form of large bubbles at a slow rate in order to maintain dissolved oxygen at a satisfactory level.

Physical and chemical determinations (dissolved oxygen, pH, alkalinity, acidity, and hardness) were made on each test concentration initially and after fish mortality or at the completion of the test. This was done primarily to detect low dissolved oxygen levels so they could be controlled if necessary and to determine other conditions which might affect toxicity.

Fish reactions were observed over a 96-hour period. From the mortality in different concentrations, 24-, 48-, and 96-hour TL_m (median tolerance limit) values were obtained. The median tolerance limit is the concentration of a chemical in dilution water which causes 50 percent mortality of the test fish. These values were obtained by straight-line graphical interpolation from points representing percent survival of fish and log concentrations of insecticide formulations which bracketed the 50 percent point (Doudoroff *et al.*, 1951).

BIOASSAY RESULTS

A summary of bioassay results for the chlorinated hydrocarbon compounds and formulations is given in Table 1. Twenty-four, 48, and 96-hour TL_m values are shown for different species of fish and different dilution waters. All values are reported as parts per million by weight (milligrams/liter) of compound or formulation as described in the previous section (Chlorinated Hydrocarbon Insecticides).

In practically all of these bioassays fish mortality definitely increased between the 24- and 96-hour periods. In a few experiments where fish were allowed to remain for periods of ten days, additional fish mortality occurred. Further experiments in which fathead minnows were exposed for twenty days to continuously renewed solutions of DDT showed that toxicity was approximately twice (TL_m value half) that obtained in 96-hour static experiments. The

TABLE 1.— TL_m (median tolerance limit) values for chlorinated hydrocarbon insecticide formulation.

Formulation	Dilution water	Kind of fish	TL_m p.p.m. (milligrams/liter)		
			24 hour	48 hour	96 hour
Aldrin, technical 88.4 percent active in acetone	Soft	Fatheads	.047	.040	.037
	Hard	Fatheads	.041	.032	.032
	Soft	Bluegills	.018	.018	.015
	Soft	Goldfish	.056	.032	.032
	Soft	Guppies	.089	.050	.037
Dieldrin, technical 90 percent active in acetone	Soft	Fatheads	.040	.018	.018
	Hard	Fatheads	.018	.018	.018
	Soft	Bluegills	.014	.0093	.0088
	Soft	Goldfish	.048	.041	.041
	Soft	Guppies	.062	.032	.025
Endrin, technical 91 percent active in acetone	Soft	Fatheads	.0018	.0013	.0011
	Hard	Fatheads	.0016	.0015	.0014
	Soft	Bluegills	.00075	.00075	.00066
	Soft	Goldfish	.0056	.0023	.0021
	Soft	Guppies	.0034	.0028	.0016
Endrin, emulsible concentrate 19.5 percent active in water	Soft	Fatheads	.0048	.0032	.0029
	Hard	Fatheads	.0068	.0047	.0038
	Soft	Bluegills	.0042	.0042	.0037
Endrin, wettable powder 75 percent active in water	Soft	Fatheads	.0039	.0029	.0026
	Hard	Fatheads	.0041	.0035	.0032
Chlordane, reference standard 100 percent active in acetone	Soft	Fatheads	.069	.069	.052
	Hard	Fatheads	.098	.069	.069
	Soft	Bluegills	.036	.032	.022
	Soft	Goldfish	.166	.087	.082
	Soft	Guppies	.56	.19	.19
Chlordane, emulsible concentrate 75 percent active in water	Soft	Fatheads	.19	.17	.17
	Hard	Fatheads	.26	.18	.18

(Continued on following page)

compounds apparently have a cumulative or chronic effect on fish.

During the course of the bioassays, physical and chemical characteristics of the test solutions (dissolved oxygen, pH, alkalinity and hardness) were not greatly changed from those of the dilution water. While dissolved oxygen was decreased in a few test solutions (attributed to the acetone solvent), sufficient oxygen was added to maintain levels of at least 4 p.p.m.

Physiological reactions of the test fish were somewhat similar for all of the compounds tested except BHC. The reaction time to most of the compounds, even in the highest concentrations, was much slower than has been observed with many other toxic compounds. In high concentrations the first visible evidence of effect occurred after 30 to 60 minutes exposure while in lower concentrations a much

longer time was required. Generally, a brief period of high excitability, during which the fish swam rapidly on the surface around the edges of the test aquaria, was followed by alternate periods of muscular spasms resulting in short jerky movements and then by short quiescent periods accompanied by partial loss of balance. This was followed by complete loss of equilibrium with the fish swimming on their backs in short jerky movements on the water surface is a circular pattern around the edges of the test jar. Death followed after varying periods, sometimes as long as 24 hours or more. A swelling in the abdominal region, especially pronounced in fathead minnows, was observed. The fish also appeared somewhat lighter in color than the controls. Fish exposed to BHC did not react characteristically but slowly sunk to the bottom of the aquaria and gradually expired.

TABLE 1.—(Cont'd).— TL_m (median tolerance limit) values for chlorinated hydrocarbon insecticide formulations

Formulation	Dilution water	Kind of fish	TL _m p.p.m. (milligrams/liter)		
			24 hour	48 hour	96 hour
Dieldrin, technical percent active in acetone	Soft	Fatheads	.134	.13	.13
	Hard	Fatheads	.084	.080	.078
	Soft	Bluegills	.042	.032	.026
	Soft	Goldfish	.72	.385	.320
	Soft	Guppies	.225	.148	.148
Dieldrin, reference standard percent active in acetone	Soft	Fatheads	.013	.0075	.0075
	Hard	Fatheads	.016	.0075	.0051
	Soft	Bluegills	.0075	.0038	.0035
	Soft	Goldfish	.0082	.0068	.0056
	Soft	Guppies	.042	.024	.020
Dieldrin, technical percent <i>p,p'</i> isomer in acetone	Soft	Fatheads	.056	.045	.042
	Hard	Fatheads	.078	.068	.045
	Soft	Bluegills	.026	.021	.021
	Soft	Goldfish	.180	.047	.036
	Soft	Guppies	.135	.072	.056
Dieldrin, screened percent <i>p,p'</i> isomer in acetone	Soft	Fatheads	.032	.026	.026
	Hard	Fatheads	.029	.027	.026
Dieldrin, recrystallized percent active in acetone	Soft	Fatheads	.066	.064	.064
	Hard	Fatheads	.040	.038	.035
	Soft	Bluegills	.066	.062	.062
	Soft	Goldfish	.120	.086	.056
	Soft	Guppies	.24	.125	.120
Dieldrin, recrystallized percent active in acetone	Soft	Fatheads	.072	.070	.062
	Hard	Fatheads	.070	.056	.056
	Soft	Bluegills	.120	.077	.077
	Soft	Goldfish	.23	.23	.152
	Soft	Guppies	.20	.145	.138
Dieldrin, technical percent <i>gamma</i> isomer in acetone	Soft	Fatheads	22	16	15
	Hard	Fatheads	15	13	13
	Soft	Bluegills	10	7.8	5.1
	Soft	Goldfish	26	21	15
	Soft	Guppies	18	18	14

TOXICITY TO DIFFERENT SPECIES OF FISH

The direct comparative 96-hour TL_m values for the ten chlorinated hydrocarbon compounds to four species of fish are shown in Table 2. All values are reported in parts per billion (micrograms/liter) of the pure compounds computed from the percentage of compound in the technical grade or reference standard material. All of the values are based on bioassays conducted under carefully standardized conditions using soft water as the diluent and at a temperature of 25°C. Many are averages of two or more replicate experiments.

Endrin was by far the most toxic of the insecticides to all species of fish. In fact, it is the most toxic chemical that has been tested in this laboratory. The very closely related compounds, aldrin and dieldrin, were considerably less toxic, showing that a slight change in chemical structure can greatly change the degree of toxicity. Toxaphene was the second most toxic insecticide, followed by dieldrin, aldrin, and then DDT. Heptachlor, chlordane, methoxychlor, and lindane were only slightly less toxic than DDT. All of the compounds tested, except BHC, would be considered highly toxic to fish and were toxic to native species in concentrations of less than 100 p.p.b. (0.1 p.p.m.).

In numerous replicate experiments with BHC, the data were highly variable. The concentrations needed to produce any fish mortality far exceeded the solubility of this compound in water. It was observed during the bioassays that when acetone solutions of BHC were added to water, much of the material precipitated and settled to the bottom of the test containers. The values for BHC given in Table 2 are based on the *gamma* isomer content (15.5 percent) and these values should be roughly comparable to those for lindane, the pure *gamma* isomer. However, these values are widely different, with the *gamma* isomer in BHC much less toxic than the pure *gamma* isomer. Apparently the other isomers in BHC either reduce the solubility of the *gamma* isomer or have a very strong antagonistic effect. Additional experiments lend credence to this theory. A concentration of 0.1 p.p.m. of lindane alone caused 100 percent mortality of fathead minnows in 24 hours. When 3.2 p.p.m. of technical BHC and 0.1 p.p.m. of lindane were added to the same test tank, no fish mortality occurred in 96 hours. A concentration of 3.2 p.p.m. of technical BHC alone produced

TABLE 2.—Comparative toxicity of chlorinated hydrocarbon insecticides to different species of fish¹

Insecticide	96 hour TL_m (median tolerance limit) p.p.b. (micrograms/liter) active agent			
	Fatheads	Bluegills	Goldfish	Guppies
Aldrin.....	33	13	28	33
Dieldrin.....	16	7.9	37	22
Endrin.....	1.0	0.60	1.9	1.5
Chlordane.....	52	22	82	190
Heptachlor....	94	19	230	107
Toxaphene....	7.5	3.5	5.6	20
DDT.....	32	16	27	43
Methoxychlor..	64	62	56	120
Lindane.....	62	77	152	138
BHC.....	2300	790	2300	2170

¹ Under standardized conditions — soft water as diluent. Temperature 25°C.

no fish mortality. BHC was by far the least toxic to fish of the compounds tested.

It is difficult to make generalizations concerning the toxicity of a group of compounds regardless of how closely they are related. Each compound has its individual characteristics and may or may not have identical physiological effects on an organism. Thus the relative toxicity to different species may not be the same, even for very closely related compounds. This fact is borne out by a careful examination of the values given in Table 2.

Bluegills are generally more sensitive to the chlorinated hydrocarbon insecticides than the other species. Compared with fathead minnows, their sensitivity is approximately equal to two of the compounds, is two or three times greater to most, and is about five times greater to one compound. Fathead minnows in turn are more sensitive to most of the compounds than goldfish and guppies. While there is no definite relationship between the sensitivity of goldfish and guppies, goldfish may be considered slightly more sensitive to the whole group of compounds. Even such closely related compounds as dieldrin and endrin, chlordane and heptachlor, and DDT and methoxychlor do not necessarily give similar toxicity relationships.

In studies of the susceptibility of trout and warm water fishes to DDT, Surber and Hofman (1949) state that "fingerling bluegill, smallmouth black bass, and black crappie were found more sensitive to DDT than largemouth bass, golden shiners and trout." On the basis of the summarized literature on the toxicity of chlorinated hydrocarbon insecticides to fish (Rudd and Gennely, 1956), bluegills apparently are among the most sensitive warm

water species. The cold water species trout and salmon are apparently no more and possibly less sensitive than bluegills. Adults of some species of fish have been reported somewhat less sensitive than fingerlings.

TOXICITY IN DIFFERENT DILUTION WATERS

The toxicity of many chemicals to fish is known to be greatly influenced by receiving water characteristics such as pH, alkalinity, and hardness, and possibly by others such as temperature, turbidity, dissolved oxygen, etc. Bioassays were conducted with two waters widely different in pH, alkalinity, and hardness but similar in other characteristics to determine if these qualities would greatly influence the toxicity of the chlorinated hydrocarbon insecticides. The soft and hard waters used (described in the section on Bioassay Methods) encompass the range in the above characteristics of most natural surface waters.

The comparative 96-hour TL_m values of the insecticides for fathead minnows in soft and hard waters are shown in Table 3. All values are reported as parts per billion (micrograms/liter) of active agent, computed from the percentage values shown in the table. Most of the toxicity values in the two types of waters are in close agreement, well within the range of experimental error that may be expected in bioassays. Two of the compounds, endrin and chlordane, appear to be slightly more toxic in soft water, while heptachlor, toxaphene, and methoxychlor are apparently somewhat more toxic in hard water. On the basis of the results, it may be concluded that pH, alkalinity, and hardness (within the range tested) have no major effect on the toxicity of the chlorinated hydrocarbon insecticides to fish. Observa-

tions during these studies also indicate that changes in dissolved oxygen levels between 3 p.p.m. and saturation have little or no effect on their toxicity. While temperature and turbidity have been reported to affect the toxicity of some insecticides, these factors were not evaluated during this study.

TOXICITY OF DIFFERENT FORMULATIONS

A limited amount of work was done to determine the comparative toxicity of different formulations of several of the chlorinated hydrocarbon insecticides, primarily to compare the toxicity of acetone solutions of the pure compounds with some formulations actually used for insecticidal purposes. It was believed that more uniform distribution of the compound into the test aquaria could be obtained by using a solution rather than an emulsion or suspension, thus producing more valid comparative data (provided the solubility of the compound in water was not exceeded in the test aquaria). While there is some disagreement among previous investigators as to the comparative toxicity of different insecticide formulations (Cope, 1949; Surber and Hoffman, 1949; Lawrence, 1950; Tarzwell, 1950; Mayhew, 1955; Tarzwell and Henderson, 1957), the consensus is that emulsible concentrates are among the most toxic.

The results of these experiments (Table 4) indicate that acetone solutions of the technical or reference grade materials produce toxicity values of similar magnitude to some emulsible concentrates and are somewhat more toxic than other formulations. Acetone solutions are therefore considered valid for comparative toxicity data.

Further work is now being done to determine the toxicity relationships between the

TABLE 3.—Comparative toxicity of chlorinated hydrocarbon insecticides to fathead minnows in different dilution waters

Insecticide	Percent active agent	96 hour TL_m p.p.b. (micrograms/liter) active agent	
		Soft water	Hard water
Dieldrin	88.4	33	28
Dieldrin	90	16	16
Dieldrin	91	1.0	1.3
Chlordane	100	52	69
Heptachlor	72	94	56
Toxaphene	100	7.5	5.1
DDT	76	32	34
Methoxychlor	100	64	35
Endane	100	62	56
TC	15.5	2300	2000

TABLE 4.—Comparative toxicity of formulations — Dieldrin, Endrin, and Chlordane¹

Formulation	96-hour TL_m p.p.b. (micrograms/liter) active agent		
	Dieldrin ³	Endrin	Chlordane
Technical in acetone	16	1.0	52
Emulsible concentrate ²	24	0.56	127
Wettable powder ²	.....	1.9	
Impregnated granules ²	36		

¹ Under standardized conditions—Fathead minnows in soft water—Temperature 25° C.

² Formulations added directly to water.

³ Values from Tarzwell and Henderson (1957).

major formulations of other chlorinated hydrocarbon insecticides.

COMPARISON WITH ORGANIC PHOSPHOROUS INSECTICIDES

A comparison of the toxicity to fish of chlorinated hydrocarbon and organic phosphorous insecticides is shown in Table 5. All values were derived from bioassays conducted under identical experimental conditions and using the same test species. Since most natural surface waters are moderately hard, the TL_m values obtained in hard water were selected for comparison. All results are reported on the basis of parts per million of the pure compound, computed from the percentage in the test material.

As can be seen from the table, all of the chlorinated hydrocarbons except BHC are more toxic to fathead minnows than the most toxic organic phosphorus compound. On the basis of these data it is apparent that the chlorinated hydrocarbon insecticides would be of considerably more significance than the organic phosphorus compounds from the standpoint of protection of aquatic life. Most of the organic phosphorus compounds also hydrolyze rapidly to nontoxic products and do not have the long-term residual toxicity characteristic of the chlorinated hydrocarbons. However, other factors such as absorption by soils and vegetation, solubility, runoff characteristics, etc. may have a bearing on the effect of field application, factors which could best be checked in field-scale experiments.

TABLE 5.—Comparative toxicity of chlorinated hydrocarbon and organic phosphorus insecticides¹

Chlorinated hydrocarbon		Organic phosphorus	
Insecticide	96 hour TL_m p.p.m. (mg/l) active	Insecticide	96 hour TL_m p.p.m. (mg/l) active
Endrin.....	0.0013	EPN.....	0.25
Toxaphene.....	.0051	Para-oxon.....	.25
Dieldrin.....	.016	TEPP.....	1.0
Aldrin.....	.028	Parathion.....	1.6
DDT.....	.034	Chlorothion.....	3.2
Methoxychlor.....	.035	Systox.....	4.2
Heptachlor.....	.056	Methyl	
Lindane.....	.056	parathion.....	7.5
Chlordane.....	.069	Malathion.....	12.5
BHC.....	2.0	Dipterex.....	51
		OMPA.....	135

¹ Under standardized conditions. Fathead minnows in hard water. Temperature 25° C.

² Values from Henderson and Pickering (1958).

The fact that some organic phosphorus compounds are extremely hazardous to humans and other mammals and are readily absorbed through the skin may, in many situations, overshadow the fact that they are less toxic to fish.

COMPARATIVE TOXICITY TO FISH, INSECTS, MAMMALS

Values for the concentration or dose of the various insecticides lethal to fifty percent of fathead minnows, houseflies, and white rats are shown in Table 6. The numerical values are not directly comparable because the route of toxicant administration is different. For fish the values are for the concentration in the surrounding medium (water) to which the fish are exposed for 96 hours with possible absorption through the respiratory tract and body surface. The other values are for single doses administered externally or internally. However, the values provide a comparison of the insecticidal efficiencies of the compound in relation to the possible effects on aquatic life through exposure in water and the effect on mammals by ingestion of water or food. Such comparative values may be useful in the selection of an insecticide for a specific purpose while giving proper regard to its effect on drinking water supplies and on fish and wildlife.

The apparent lack of a definite relationship between the values for the different animals suggests that fish bioassays cannot be used to predict toxicity to mammals and that, conversely, mammal tests cannot be used to predict toxicity to fish. To determine the possible effects on fish and wildlife, both types of studies are necessary.

APPLICATION RATES WHICH MAY PRODUCE FISH MORTALITY

The 96-hour TL_m values of the insecticides to bluegills and the computed rates of application to achieve these concentrations in water three feet deep are shown in Table 7. The three-foot-deep value was selected because it approximates the average depth of many farm ponds and smaller streams and also because an acre three feet deep is approximately one million gallons.

It can be seen that normal rates of application for insect control on land areas (1, 2, or more pounds per acre), if allowed to react

water surfaces, would be highly toxic to fish, at least for most of these compounds. Some would be highly toxic at application rates normally applied to water surfaces for mosquito control (0.1 or more pounds per acre). While not much information is available on the insecticide content of runoff waters from insecticidally treated land areas, runoff from areas treated with dieldrin and endrin have been found to be toxic to fish.

TABLE 6.—Comparative toxicity of chlorinated hydrocarbon insecticides to fish, insects and mammals

Insecticide	Fathead minnows ¹ 96 hour TL _m (milligrams/ liter)	**Houseflies Topical LD50 (micrograms/ gram)	White Rats Oral LD50 (milligrams/ kilogram)
Endrin.....	.0013	—	17.8*
Toxaphene.....	.0051	31.0	90*
Dieldrin.....	.016	1.1	46*
Aldrin.....	.028	1.6	67**
DDT.....	.034	8-21	113*
Methoxychlor.....	.035	—	6000**
Heptachlor.....	.056	1.6	100*
Chlordane.....	.056	1.0	125**
Endodane.....	.069	4.0	335*
BHC.....	2.0	—	1000**

¹ Under standardized conditions—Hard water—Temperature 25° C.

* Male white rats under standardized conditions. From Technical Development Laboratories (1956A).

** Values from Metcalf (1955).

Previous work with DDT has indicated that concentrations that are toxic in aquarium experiments are not necessarily toxic under field conditions, although the differences are small. These differences have been attributed to absorption of the toxicant by soils and vegetation, incomplete mixing, etc. However, the TL_m values given in Table 7 are concentrations that produce 50 percent mortality of a moderately sensitive fish in a relatively short period. Other fish or food organisms may be more sensitive and the time of exposure may be longer. Thus the concentration safe for aquatic life may be considerably less than the value given, possibly as little as one-fifth or one-tenth of this value. The rates of application given in the table would probably cause fish mortality under most conditions and certainly could not be construed safe for aquatic life. Considerable additional research is needed before reasonably safe concentrations or application rates can be established for the chlorinated hydrocarbon insecticides under all conditions.

TABLE 7.—Amount of chlorinated hydrocarbon insecticide when applied to water surface that may produce fifty percent fish mortality

Insecticide	96 hour TL _m p.p.b. (micrograms/liter) active agent ¹	Pounds per acre applied to the surface of water 3 feet deep to reach the TL _m concentration
Endrin.....	0.60	0.005
Toxaphene.....	3.5	0.03
Dieldrin.....	7.9	0.07
Aldrin.....	13	0.11
DDT.....	16	0.13
Heptachlor.....	19	0.16
Chlordane.....	22	0.18
Methoxychlor.....	62	0.51
Lindane.....	77	0.63
BHC.....	790	6.4

¹ Under standardized conditions—Bluegills in soft water. Temperature 25° C.

NEEDED RESEARCH

Insect control by chemicals is generally considered a necessity for protection of humans against disease carrying and annoying insects as well as for protection of crops, livestock and forests. Money, brainpower, and manpower have been invested heavily in research for the development of suitable chemicals and methods for their effective use. A much lesser investment has been made for research into the possible harmful effects that insecticides may cause. The problem of insect control without excessive damage to certain land or water uses is not insurmountable but will require more attention than it is receiving at present. Extensive laboratory and field research is needed in such categories as the development of selective toxicants and methods and timing of application to provide for minimum effects on fish and wildlife. The new Pesticide Research Bill (85-582) is a step in the right direction but further effort is needed by manufacturers and users of insecticides, control agencies, and others.

Areas of needed research on the effects of insecticides on aquatic life suggested by the present study include the following:

- (1) Relative toxicity of different formulations.
- (2) Effects of long-term exposure.
- (3) Toxicity of runoff from insecticidally treated areas, with reference to different soil types, land cover, rainfall intensity and frequency, etc.

- (4) Relative toxicity to other important warm and cold water fish species, including effects at different life cycle stages and toxicity to major food organisms.
- (5) Effects of other water quality characteristics, especially temperature, turbidity and organic content.
- (6) Development of antagonistic materials that may be added to insecticide formulations that reduce the toxicity to fish with little effect on insecticidal activity.
- (7) Use of fish bioassay as an analytical tool for determining insecticide residuals. Identification of the toxicant by physiological response of fish.

Further investigation is also needed concerning the possible effects on human health and on other land and water uses. It is certainly preferable and possibly essential that such investigations be made in the developmental stages of an insecticide rather than after its widespread application.

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Refinements of Equipment and Procedures in Electro-Fishing

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ABSTRACT

An electrofishing device that is mounted on a boat is described. This "boom seine" is 3 times more efficient at night than during the day. The catch of the boom seine in a Missouri impoundment is compared with the catch from nets. It is selective toward the centrarchids (except white crappie) in waters where nets are selective toward white crappie, gizzard shad, white bass and freshwater drum. Selectivity is related to the behavior of the fishes and habitat where the fishing is done.

INTRODUCTION

Electrofishing has proved to be a valuable tool in fishery research and is presently a rapidly developing method for taking fish. Refinements in equipment, procedures, and interpretation of results of electroseining therefore, merit discussion. The purposes of this note are to describe an improved rig for electroseining, to compare results of nocturnal and diurnal electroseining, and to discuss species selectivity of the electric seine as compared to other seines fished in the same waters.

THE BOOM SEINE

The boom seine described (Figure 1) is a modification of Funk's (1949) electric stream seine. It is mounted on the front of a square-stemmed 16-foot aluminum Arkansas Traveler boat. The mount consists of two booms, 2 by 2 inches by 12 feet which are loosely bolted to the gunwales 4½ feet back from the stem. They flare outward in front of the boat and rest on a 2 by 2-inch cross piece set across the gunwales a foot and a half back from the stem. Across the outer ends of these booms is a 2 by 2-inch, 12-foot outer boom is bolted and from this the electrodes are suspended at foot intervals.

The electrodes are alternated as to electrical polarity. They are 12 feet long and are made of ¼ inch hollow braided metal bonding of the type used to shield ignition systems. Discard-er rubber covered cable with an outside diameter of ¼ inch is inserted into the hollow center of the bonding and serves to stiffen the

electrodes. They may be weighted by soldering lead seine weights at their ends. Electrodes are soldered to positive and negative insulated leads of No. 14 rubber-covered cable which extend along the outer boom and are connected to a gasoline driven Homelite alternating current generator which is rated at 1500 watts and 120 volts.

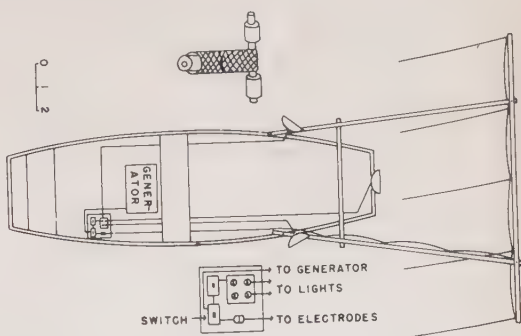


FIGURE 1.—A diagram of the "boom seine". Inserts show the wiring of the junction box and switches and the way the braided wire electrodes are soldered to the leads. Inserts are not to scale.

The major modification of the electric seine of Funk (1949) is that electrodes are suspended from a boom at the front of the boat rather than from a cable which was carried by wading operators. This rig differs from Loeb's (1957) in that four electrodes are arranged in a linear series along the outer transverse boom, as opposed to placement of 2 electrodes on either side of the boat, the anterior pair 12 feet forward of the posterior pair.

Illumination for collecting fish at night is supplied by three 100 watt lights mounted on clamp-on reflectors. One reflector is placed on the stem and one on each gunwale.

A junction box and switches, mounted on a portable plywood panel, are located im-

¹Contribution from the Missouri Cooperative Wildlife Research Unit: U. S. Fish and Wildlife Service, Wildlife Management Institute, Missouri Conservation Commission, Edward K. Love Foundation, and University of Missouri cooperating.

mediately in front of the oarsman. Leads from the generator are run through the switches to the junction box and the lights are plugged into this. A switch is placed between the electrodes and the junction box so that current to the electrodes can be cut off without affecting the lights. This switch is placed in easy reach of the oarsman for use in emergency.

In operation, one man picks up stunned fish from the stem with a long-handled dip net. A second man rows from the stern while facing forward. The boom seine is most effective when moved very slowly close to the shore in water less than 10 feet deep. The oarsman can guide the electrodes in and around rocks and stumps to insure coverage of all likely fish habitat.

NOCTURNAL VERSUS DIURNAL
ELECTROSEINING

Loeb (1957) showed clearly that electroseining for some species of fishes, was much more effective at night than during daylight hours. Nevertheless, many fishery workers do not realize how great the increase in effectiveness of this tool is when used at night. Our data serve to emphasize this point.

In June, 1953, this electric boom seine was tested for three days along steep rubbly shores, brush-strewn banks and coves, and shallow muddy shores of a Missouri impoundment, Lake of the Ozarks. The water at this time was fairly clear and Secchi disc readings averaged 18 inches. Each area sampled was fished for approximately one daylight hour, and a similar length of time the same night. Three additional nocturnal tests were made the following October.

Nocturnal electrofishing was more than 3 times more efficient than diurnal fishing (Table 1). Average catch for diurnal electro-

fishing in June was 98 fish per hour, and for nocturnal electrofishing on the same day was 346 per hour. In October the night fishing catch in the same area averaged 305 fish per hour.

An accurate estimate was made of the number of fishes shocked but not recovered. The fishes taken represent approximately half of those shocked. The rest either sank out of sight or came up behind the boat and no determined effort was made to capture them.

Twenty-one species of fishes were captured by both day and night electrofishing. However, white bass, walleye and white crappie, all of which are abundant in the reservoir, were taken only at night. Clearly, the results of electrofishing for any one species are dependent on the diel movements of the species. This is a factor in the efficiency and selectivity of the gear.

In our experience and that of others (Bowman, *personal communication*) similar differences in nocturnal and diurnal electroseining appear in stream fishing.

SELECTIVITY OF THE ELECTRIC SEINE

One means of evaluating species selectivity of the electric seine is to compare results of electric seining with the catch of gill nets and hoop nets fished in the same body of water at the same time (Table 2). In the present case, numbers of fish taken are not directly comparable since the unit of effort was not constant. However, selectivity of the two kinds of gear can be compared. The gill nets (mesh size 1-inch to 2½-inch bar measure) were set perpendicular to the shore and extended from the shoreline to a depth of 30 to 40 feet. Hoop nets were set parallel to the shoreline at depths of 5 to 25 feet. The nets were fished overnight for 3 or 4 days a week in 1950 and overnight for 5 days in 1953. The electric boom seine was fished for only 9 hours along the shore. To facilitate analysis, the species were arbitrarily placed in three groups: the four most abundant species taken by the nets, white crappie, gizzard shad, white bass, and freshwater drum; the centrarchids exclusive of the white crappie; and others (Table 2).

Electroseining, when compared with netting, was selective against white crappie, gizzard shad, and white bass, and was selective toward the basses and sunfishes. The percentage of the total catch, by nets, for the four most abundant species during June–September, 1950, and October, 1953, was 91 and 78 re-

TABLE 1.—Number of fish of all kinds taken per trip from the same water area of Lake of the Ozarks by diurnal and nocturnal electrofishing in June 1953 and by nocturnal electrofishing in October 1953

	June 14-16		Oct. 15-17
	Day	Night	Night
Trial 1	72	238	371
Trial 2	173	646	348
Trial 3		328	196
Total number	245	1212	915
Effort in hours	2.5	3.5	3.0
Fish per hour	98	346	305

TABLE 2.—Comparison of the number of fish caught and percentage composition of the total catch by netting¹ and electrofishing

Species	Netting June–September, 1950		Electrofishing June, 1953		Netting October, 1953		Electrofishing October, 1953	
	Number	Percent of total	Number	Percent of total	Number	Percent of total	Number	Percent of total
<i>Ambloplites annularis</i>	3191				327		1	
White crappie								
<i>Parachanna cepedianum</i>	282		27		96		58	
Gizzard shad								
White bass	12		21		141		20	
<i>Micropterus salmoides</i>	165		203		20		30	
Subtotal	3650	91	251	17	584	78	109	12
<i>Micropterus salmoides</i>								
Mouth bass	1		25				124	
<i>Micropterus punctulatus</i>								
Spotted bass			112				24	
<i>Micropterus macrochirus</i>								
Gill sunfish	66		424		10		258	
<i>Micropterus cyanellus</i>								
Green sunfish			357				136	
<i>Micropterus megalotis</i>								
Yellow perch	1		132		4		108	
Subtotal	68	2	1050	72	14	2	650	71
Others	276	7	156	11	147	20	156	17
Total	3994		1457		745		915	

¹Op nets and gill nets of various mesh sizes.
Includes 12 other species, generally forage fishes exclusive of minnows.

actively, and for the centrarchids only 2 and percent. However, the percentage of the total catch by electrofishing for the four most abundant species during June and October, 1953, was only 17 and 12 respectively, whereas it was 72 and 71 percent for the centrarchids.

The selective action of the boom seine toward most of the centrarchids can be explained on the basis of their depth preferences and movements. The basses and especially sunfishes were observed by us to move in toward the shore at night and rest on the bottom in very shallow water where they are most vulnerable to the electric seine. The white crappie seeks deeper water than the other centrarchids and so is not reached by the electrodes. It may be that recovery of white crappies in deeper water is hampered by turbidity.

White bass, gizzard shad and other fishes, on the other hand, do not commonly inhabit the immediate shoreline and are therefore less vulnerable to the electric seine. Species composition of the catch is also influenced by the habitat of the fishes and the type of habitat fished. Centrarchids were more abundant over a rubble bottom in shallow water and the young of drum and carpsuckers were more abundant over a mud bottom in shallow as well as deep water.

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Yearling Liberations and Change of Food as Effecting Rainbow Trout Yield in Paul Lake, British Columbia¹

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ABSTRACT

Some effects of the introduction of reidside shiner, *Richardsonius balteatus* (Richardson), on the rainbow trout, *Salmo gairdneri* Richardson, in Paul Lake from 1952 to 1957 are considered together with results of yearling trout liberations since 1953. Changes in the diet of rainbow trout from invertebrates to reidside shiners, already noticeable in 1952, have since intensified. By 1956, shiners comprised over 90 percent of the summer diet of trout over 35 centimetres in length. In the diet of trout larger than 25 centimetres, shiners replaced plankton, amphipods and other bottom organisms to a marked degree. Trout under 25 centimetres utilized more shiners than previously, but in lesser proportion than the larger trout.

A program of yearling trout liberations since 1953 has shown considerable success, these trout forming up to eight percent of the anglers' catch in the fall of the year of liberation and as high as 50 percent in the following spring. Hatchery fish of a given age were less variable in size and grew faster than wild fish of the same age. Both wild and hatchery trout showed growth rates in their second and third years suggesting increased use of shiners as food. Wild fish which began the year at fork lengths over 17 centimetres in 1955 and 1956, had growth rates equivalent to wild fish in years prior to the introduction of shiners. The contribution of yearling liberations, growth rates of wild and hatchery trout and the effect on the fishery of the changing relations of rainbow trout and reidside shiners are discussed.

INTRODUCTION

The sport fishery for rainbow trout in Paul Lake has been studied over a long period of years. The early history was recorded by Mottley (1932). In 1909 the barren lake was stocked with 5000 rainbow trout fry and by 1920 there was a large unexploited population. By 1925 competition had resulted in a decrease in size of trout, but by 1931 a decrease in total catch, catch per unit effort, and the number of trout in the spawning run indicated population depletion. In 1931 the maximum weight of trout was nine pounds. Mottley concluded that the spawning stream had insufficient flow to provide incubation and transportation for the necessary annual production of fry. After his investigation the lake was stocked annually with 200,000 fry. By 1937 the total catch had stabilized between 9000 and 10,000 fish per year. The average weight of the trout was one pound, so that the annual

total crop was approximately 10,000 fish or 10 pounds per acre (Mottley, 1940). The rate of production continued to 1949 (Table 1). During both the 1936-37 and 1946-47 periods the catch was made up chiefly of 1-, 2- and 3-year old fish in roughly equal proportions, with a small fraction of the catch of older fish (Table 2).

Between the years 1945 and 1950 the reidside shiner (*Richardsonius balteatus*) entered the lake from the drainage upstream where had previously been introduced. Shiners cor

TABLE 1.—Anglers' catch of trout in Paul Lake, 1932-1957

[Figures for 1932-1949 from Larkin *et al.* (1950). Figures for 1954 and 1955 from Smith (1955). Production of trout in Paul Lake in 1955 from manuscript report to British Columbia Game Commission, Dec. 1955, 7 pp.]

Year	Total catch of trout	Catch per boat-day ¹	Average weight (pounds)
1932	3,000	4.0	1.49
1936	10,000	9.0	1.00
1949	11,000	3.7	1.01
1954	2,349	2.1	1.0 (est.)
1955	10,043	4.3	1.0 (est.)
1956	11,330	2.5	1.1 (est.)
1957	8,700	3.7	1.2 (est.)

1. Based in part, on material derived from Crossman, E. J., 1957. Factors involved in the predator-prey relationship of rainbow trout, *Salmo gairdneri* Richardson, and reidside shiners, *Richardsonius balteatus* (Richardson), in Paul Lake, British Columbia, Ph.D. Thesis University of British Columbia.

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¹ One boat-day is equivalent to 10 hours fishing.

with small trout for food and space, and shiners preyed on trout fry and these effects were only in part compensatory predation of large trout on large shiners (Larkin and Smith, 1954). Between 1948 and 1954 total annual catch declined from approximately 10,000 trout to less than 2400. By 1954 and 1955 most yearlings and many two-year-olds were not large enough to enter the fishery and the catch was chiefly made up of three years old and older.

FIG. 2.—Percentage age-composition of the angler's catch of rainbow trout from Paul Lake for three years between 1936 and 1956

Year	Percentage of sample of anglers' catch by age-groups				
	I	II	III	IV	V
1937*	25.9	39.8	24.2	9.1	1.0
1949*	34.0	34.4	26.0	5.3	0.3
	1.3	18.4	60.4	19.9	
1956	6.1	68.9	20.5	4.5	

* From Larkin *et al.* (1950)

* From Larkin and Smith (1954)

Since 1954 the lake has been stocked each spring with marked (fin-clipped) yearling trout (about 40 to the pound) and no fry are liberated. In the autumn of 1953 a large planting was made of 10,000 unmarked yearling fry (about 600 to the pound). This paper reviews the effects of these plantings on the trout fishery of the lake.

CATCH OF LIBERATED YEARLING TROUT

In the marked yearling trout planted from 1954 to 1956 the majority of those caught were taken by anglers over a year after liberation (Table 3). Only a small fraction of the trout liberated in 1955 were captured as yearlings in the late summer of 1955. Similarly only a small proportion of the marked fish caught in 1956 were from the 1956 liberation.

Marked fish that had been liberated the previous year contributed substantially to the catch in each of the summer months of 1955 and 1956. In both years the proportion of marked fish was highest in the early part of the season (approximately 50 percent), declining to roughly 20 percent in midsummer and rising to over 30 percent in early September.

In 1955 total catch of trout rose to approximately 10,000 and the catch per unit of effort, 4.3 fish per boat-day, was double

that of 1954 (Table 1). Total catch of all trout in 1956 rose to approximately 11,000 but the catch per unit of effort dropped to 2.5 fish per boat-day.

Determination of total catch became increasingly difficult after 1954 because there were many points of access to the lake instead of one as previously. The best estimate of catch for 1957 was about 9,000 trout, but this estimate is subject to considerable error.

The percentage of marked trout in the anglers' catch was somewhat lower in the spring of 1957 (May, 27 percent; June, 34 percent), than in 1955 and 1956 and remained lower throughout the 1957 season. Possible explanations are: decreased survival of planted marked fish in the larger population; intensive removal of marked fish in previous years; and varying success of individual plantings, such as is cited by Burdick and Cooper (1956). A greater number of unmarked fish in the catch may also indicate increased survival of wild fish or increased production of young in the spawning stream since the cessation of egg collecting activities in 1953 or it might be partly attributable to the liberation of 10,000 unmarked fingerlings (600 per pound) in 1955.

Although in recent years, some liberated yearlings entered the fishery as Age-group I fish in August of the year of liberation, such yearlings did not contribute as much to the catch in recent years as they did in years prior to the entry of reddsides shiners into the lake. Two- and 3-year-old trout constituted nearly 90 percent of the anglers' catch in 1955-56 (Table 2). Increased production of rainbow

TABLE 3.—Contribution of marked trout to the anglers' catch in Paul Lake — 1955 and 1956

Year and month	Number of fish in sample	Marked fish as percent of sample			
		Liberated 1954	Liberated 1955	Liberated 1956	Total
1955					
May.....	24	54	—	—	—
June.....	232	36	—	—	—
July.....	271	30	—	—	—
August.....	175	12	11	—	23
September ..	113	16	20	—	36
(half month)					
1956					
May.....	169	11	38	—	49
June.....	201	16	31	—	47
July.....	199	5	20	—	25
August.....	176	7	12	1	20
September....	94	7	19	8	34
(half month)					

trout in Paul Lake, from a low point in 1954 to a level comparable to the earlier period when food and space were utilized by trout alone, is largely attributable to liberations of hatchery-reared yearling trout.

CHANGE IN DIET OF RAINBOW TROUT DURING THE 1946-1956 PERIOD

The effect of reidside shiners on population size and growth rate of trout was accompanied by a change in the feeding habits of rainbow trout. There was a gradual but steady increase in the amount of predation, by large trout in particular, on reidside shiners, and an apparent replacement by shiners of certain food items previously consumed.

According to Larkin *et al.* (1950) during the period 1946 to 1949 there were in Paul Lake, no significant dietary differences among trout longer than eight inches (20 centimetres). In these years amphipods (*Gammarus* and *Hyalella*) made up much of the large quantities of bottom organisms eaten, particularly in the spring and early summer. Plankton comprised roughly two-thirds of the diet in July, August and September. No fish were found in the stomachs of trout taken in 1946-1949.

Larkin and Smith (1954) state that by 1952 there were marked changes in the trout diet. Amphipods had become a negligible food item for all sizes of trout. Fish was the main food of trout over 30 centimetres long from July to September, and constituted a substantial proportion of the diet of trout from 25 to 30 centimetres. Fish were also recorded occasionally from the stomachs of smaller trout from 20 to 25 centimetres long. In 1952, shiners taken by trout were almost always quite large, and shiner fry were found only rarely in the trout stomachs.

For the purpose of the 1955-56 study, stomach content components were categorized as: (1) shiners; (2) plankton; (3) bottom organisms ("bottom fauna plus aquatic insects" in the data of Larkin and Smith 1954); (4) surface organisms ("terrestrial insects" in the data of Larkin and Smith, 1954; and (5) miscellaneous. "Plankton" included all zooplankton except bottom dwelling amphipods. "Bottom organisms" included amphipods, *Hirudinea*, gastropods and immature aquatic insects of the orders Odonata, Diptera, Trichoptera and Ephemera. Surface organisms included adult insects. Unidentifiable material and plant and bait remains were included in the miscellaneous category.

Volume of stomach contents in each category was determined for each stomach by displacement of water. Total volume is the sum of category volumes. In 1955 the number shiners in each trout stomach was recorded as the length and volume of each shiner. Positive identification of shiner remains in the stomachs of trout was possible because shiners retained their body shape and characteristics as long as 14 hours after being eaten, and because shiners in Paul Lake were heavily parasitized by an intestinal cestode, *Ligula intestinalis*. According to Bangham and Adams (1954) this cestode does not parasitize rainbow trout in Paul Lake. Almost invariably when identification was not possible from body shape and size, the presence of *Ligula* allowed identification of shiner remains.

Seventy-six trout were obtained in December 1955 and January 1956 from gillnets set under the ice on shoals. Stomach contents from these were used to compare summer and winter diets.

Summer diet of rainbow trout

Summer diet of rainbow trout is shown in Table 4 as the percentage volume of various food items consumed by trout in the three size-groups during the May-September periods in 1955 and 1956. This table is an extension of Table 1 of Larkin and Smith (1954), which summarizes similar data for 1946-1952. Stomach contents of trout taken in 1955 and 1956 indicated an extension of the 1952 feeding pattern. There appeared to be a continued and gradual increase in the amount of fish consumed. The trout taken in 1955 and 1956 fall into three length groups (15 to 24.5, 25 to 34.5 and over 35 centimetres fork length) according to the importance of shiners in the diet. Feeding habits differed from 1946-1949, when there was no clear difference in the diet of trout of various sizes.

As consumption of shiners increased during the 1946-1956 period, plankton in the diet had decreased almost proportionately (Figure 1). Although shiners appeared in Paul Lake in 1945, none were seen in the stomachs of trout until 1950. Consumption of bottom organisms by trout in the middle size range had greatly increased since 1952 while consumption of surface insects, formerly important, had declined. Gammarids, which were earlier abundant, were rare in 1955 and 1956 when the bottom fauna was mainly dragonfly nymphs, snails and chironomid pupae.

Seasonal variations in the diet were much the same for the three size groups of trout over the 1952-1956 period but the change in importance of individual items occurred at different times in varying degrees in the three size-groups. From 1952 to 1956 bottom organisms comprised over 80 percent of the diet in May and over 60 percent in June. Plankton which previously predominated in the diet of all trout during July, August, and September, was found only in the small trout in 1955-1956, and had been replaced by shiners in the large trout and by bottom organisms in trout of the middle-size range. The change to a predominance of bottom fauna and shiners in the diet of 25-34.5 centimetre fish since 1952 and the concurrent decrease in the importance of plankton is shown in Figure 2. Seasonal variation of food types is best demonstrated by this middle-size group in which trout begin to feed mostly on shiners.

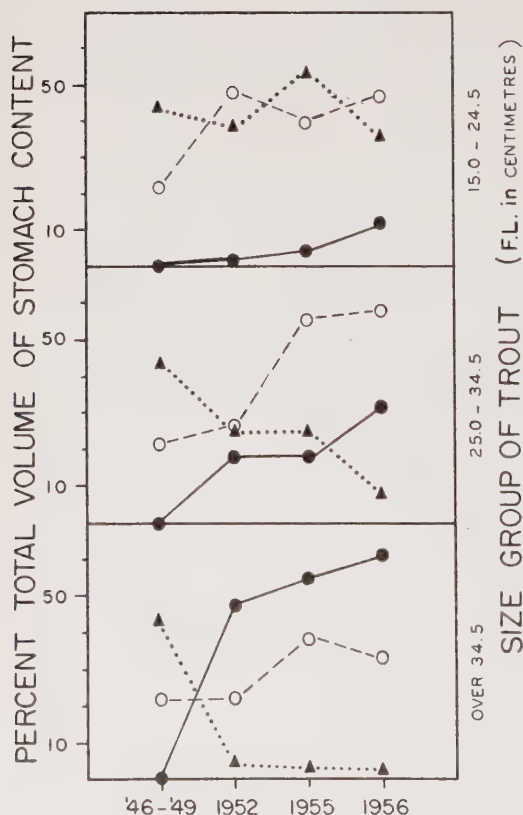


FIGURE 1.—Percentage of total volume of stomach contents for trout of three size-groups. Food items: shiners (●); plankton (triangle); and bottom organisms (○). Data for 1946-1952 from Larkin and Smith (1954).

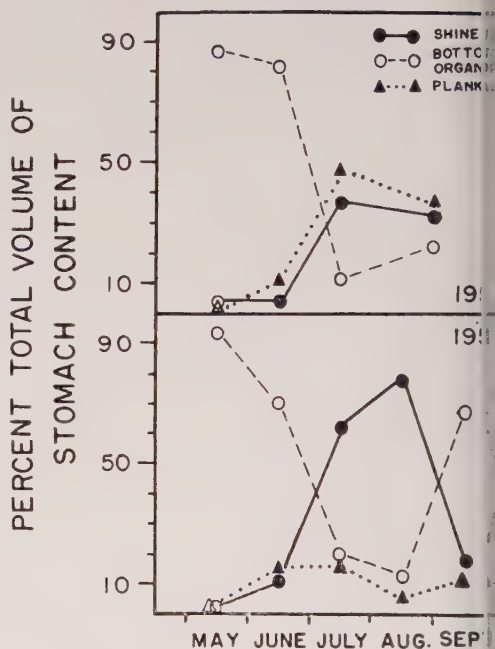


FIGURE 2.—Seasonal variation in the contribution of shiners, plankton, and bottom organisms to diet of rainbow trout 25-34.5 centimetres fork length in 1952 and 1956. The 1952 data is from Larkin and Smith (1954).

In August and September 1952 shiners constituted 79 percent of the stomach contents of fish over 34.5 centimetres. In August 1956, 94 percent of the volume of stomach contents of this size-group was shiners. While there was an increase since 1952 in the volume of shiners consumed by large trout, this increase was not as noticeable as that in the middle size-range (25 to 34.5 centimetre) group. The diet of the smallest size-group in 1956, while showing an increase in the amount of shiners consumed, was still dominated by bottom organisms and plankton as it was prior to 1952.

In 1956 there was a relationship between size of trout and volume of shiners eaten. There was a marked decrease in the volume of plankton consumed by trout over 24.5 centimetres (Figure 1). While there were increases in amount of shiners consumed by all size-groups between 1946 to 1956, this increase was more marked for 15 - 24.5 centimetre trout. In 1952 shiners were an important dietary item for trout over 35 centimetres and the increase in consumption of shiners by the smaller trout from a low level in 1952 indicates that the size at which trout begin to prey on shiners may be gradually decreasing.

The increased importance of the contribution of shiners to the diet of trout over 35 centimetres long is also apparent; average total volume of stomach contents increased from approximately 1.5 cc. in 1946 to 6.5 cc. in 1952 and 7.9 cc. in 1956 (Figure 3). In the middle size-range (25.0-34.5 centimetres) there was an increase of about 1 cc., but in smaller trout there was no increase in the average volume of stomach contents over 1952. In 1956 the average for the 15.0-24.5 centimetre-group was lower than that in 1947 when shiners had not, as yet, become well established.

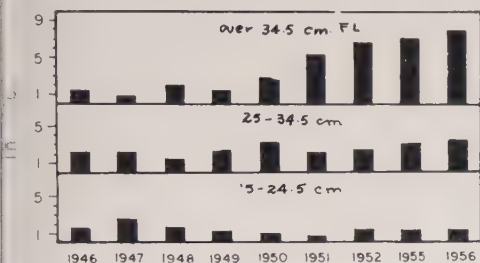


FIGURE 3.—Average volume of stomach contents of rainbow trout from Paul Lake, 1946-1956. Data from 1946-1952 from Larkin and Smith (1954).

Winter diet of rainbow trout

Stomach contents of 76 trout taken in gill-nets in the winter of 1955-1956 showed that bottom fauna dominated the winter diet of all sizes of trout. Bottom fauna constituted 94 percent of the diet of the smallest trout, 93 percent for the middle-size range and 83 percent for the largest trout.

In winter, shiners were not found in stomachs of trout 15-24.5 centimetres long. They constituted only 0.1 percent of the diet in the middle-size range (25-34.5 centimetres); as indicated by a single stomach from a group of 46 trout. Even the largest trout, which are the greatest consumers of shiners in the late summer, had only 10 percent shiners in the total volume of winter food. Of the 26 large trout taken in winter, only one had eaten shiners and these had a volume of 25.7 cc.

Size of trout and size of shiners eaten

A direct relationship was noted between the size of trout and size of shiners eaten (Table 5).

Most (79 percent) of the shiners eaten by trout longer than 45 centimetres were more than 7.5 centimetres long. Sixty percent of shiners eaten by trout over 25 centimetres in length were longer than 5 centimetres. It ap-

pears that large trout prey mostly on large shiners and utilize small shiners to a negligible extent. Even smaller trout, those in the 15- to 25- centimetre category, when they feed on shiners take those longer than 2.5 centimetres (Table 5) and do not utilize the abundance of smaller shiners 1 to 2.5 centimetres in length.

Angling success using shiners as bait

Experimental angling showed that trout caught were longer and the volume of shiners in the stomachs greater when shiners were used for bait than when the trout were caught on artificial bait such as flies, plugs or spinners. A random sample of 35 trout caught with artificial tackle was compared with 35 trout taken with shiners. The mean size of trout taken with artificial bait was 42.7 centimetres, and the mean size of trout taken with shiners was 46.3 centimetres. The mean total stomach volume of trout caught with shiners was 25.2 cc. and the mean volume of shiners eaten was 25.1 cc. as compared to means of 12.1 cc. and 11.3 cc. for trout taken with artificial bait. A "t" test of the difference in volume of shiners in the stomachs of the two groups of trout showed a significant difference ($p < .01$).

The catch per unit of effort, using shiners as bait during July and August (periods of heavy predation), was considerably higher than that for artificial bait. The catch as numbers of trout, per man hour, was five times greater (0.9 as compared to 0.18 fish), and nine times greater (1.6 as compared to 0.18 pounds) in terms of weight).

GROWTH OF TROUT

Growth rates of trout in Paul Lake have changed noticeably since the introduction of reidside shiners. Larkin and Smith (1954) tabulated size of trout at various ages in Paul Lake from 1943 to 1951 and for these years

TABLE 5.—Number of shiners of various size consumed by different sizes of trout in 1955 and 1956

Trout size (Fork length centimetres)	Number of shiners in size group Shiner size (Fork length in centimetres)					
	1-2.5	2.5-5.0	5.0-7.5	7.5-10	10-12.5	
15-24.5	1	3	2	—	—	
25-34.5	13	31	62	10	—	
35-45	1	8	30	33	1	
45-55	—	3	6	31	2	
Totals	15	45	100	74	3	

concluded that growth rate during the first year had not changed significantly. The average length of trout of Age-group I remained at about 8.2 centimetres. The length of trout of Age-group II declined from about 24 centimetres to 17 centimetres during the five years from 1945 to 1950. Predation on shiners was associated with accelerated growth rate of larger fish in their third year.

Table 6 gives length-age data from Larkin and Smith (1954) for trout taken from Paul Lake during the period 1947 to 1950 together with additional data on wild fish in 1951 and 1952, and on wild and on marked hatchery-raised fish in 1955 and 1956. Selection of faster growing fish by the fishery, described by Larkin and Smith is still evident. In every year those fish which were caught at the earliest age were those which had grown fastest. The same is true if a year class is followed through successive years of the fishery. Selection of the larger fish in any year class was more intense for the wild fish than for the hatchery-raised fish. In 1955-56 the calculated lengths of wild trout at Age I for fish caught at Age I plus, Age II plus and Age III plus were respectively 11.0, 6.6 and 4.9 centimetres.

TABLE 6.—Fork length (centimeters) at capture and calculated lengths at the end of the several years of life for trout caught from Paul Lake in the years 1947 to 1952, and for wild and marked hatchery-reared trout to 1955-56

Year of capture	Age group at capture	Number of fish	Length at capture		Calculated length at end of year of life		
					1	2	3
1947	I	19	24.2	9.6	.....	.....	.....
	II	12	32.2	8.9	24.8	.....	.....
	III	13	36.1	7.9	22.3	30.4	.....
1948	I	36	23.9	10.3	.....	.....	.....
	II	93	36.6	9.5	29.7	.....	.....
	III	28	42.2	7.9	23.3	34.7	.....
1949	I	33	22.0	9.9	.....	.....	.....
	II	35	32.9	8.1	24.4	.....	.....
	III	13	38.8	8.6	23.4	33.2	.....
1950	I	13	21.4	12.7	.....	.....	.....
	II	113	28.3	7.5	21.5	.....	.....
	III	14	35.5	7.4	18.8	31.3	.....
1951	I	36	22.1	11.7	.....	.....	.....
	II	405	26.1	8.7	19.2	.....	.....
	III	134	31.3	7.0	17.7	27.6	.....
1952	I	9	23.3	10.1	.....	.....	.....
	II	121	25.5	7.8	16.6	.....	.....
	III	308	31.1	7.3	15.9	25.0	.....
1955-56	I	13	23.9	11.0	.....	.....	.....
	I marked	4	22.4	8.2	.....	.....	.....
	II	162	29.8	6.6	20.6	.....	.....
	II marked	50	32.6	7.1	25.0	.....	.....
	III	76	35.8	4.9	14.5	29.6	.....
	III marked	6	38.9	6.9	19.2	32.8	.....

The same statistics for hatchery-raised fish were 8.2, 7.1 and 6.9 centimetres. Apparently range in length and growth rate of wild fish is greater than that for the hatchery-raised fish. There is no way of combining the data for fish caught at various ages to give a single estimate of average size at Age I. However, on a small fraction of wild and hatchery fish were taken as yearlings by the fishery, and for both the fish caught at Age II plus and Age III plus, the hatchery fish were larger at all ages. It can be concluded that on the average hatchery fish were almost certainly larger at liberation than wild fish of the same age.

Both wild and hatchery-raised trout show similar growth rates in the second and third years which suggest increased use of shiners as forage since the 1951 and 1952 period. This feature is illustrated in Figure 4 which shows instantaneous growth rates related to size of wild trout. As indicated by Larkin, Terpin and Parker (1957), growth rates for 1952 for all but the very largest sizes of trout were decreased by the effects of competition by shiners. In the 1955 and 1956 period on the smallest trout showed an appreciable increase in growth rate from the pre-shiner period. Fish which began the year at fork length over 17 centimetres in 1955 and 1956, had growth rates equivalent to those of comparable size in the years prior to introduction of shiners. Apparently fish over 17 centimetres at the beginning of a year, begin eating shiners during the midsummer period and rapidly grow into the range of 25 to 35 centimetres.

Growth data for the large fish warrants special mention. The data presented in Table 6 and Figure 4 are not representative of large fish of the anglers' catch. Larger older fish have commonly spawned and desorption of scale margins prevents back calculation of length at previous ages. This category roughly includes 50 percent of the 3-year old fish and all of the trout 4 years old and older. The latter constituted 19.9 percent of the 1952 catch and 4.5 percent of the 1955-1956 catch. Larkin and Smith (1954) state that small samples of 4-year-old fish in 1951 indicated that growth rate of these larger fish was being accelerated by predation on shiners. This trend is verified by data for recent years and anglers' catches have included specimens as large as 61 centimetres.

Fish over 45 centimetres fork length made up 4 percent of the total catch in 1955, 9 percent in 1956 and 13 percent in 1957. The

numbers of large fish produced in these years matched only in the early period of development of the Paul Lake fishery, as described by Cottley (1932).

TROUT-SHINER RELATIONSHIPS AND THEIR EFFECTS ON THE FISHERY

Production of rainbow trout in British Columbia, as number or weight of trout taken by angling, is greater in lakes which contain only trout than in lakes where trout are subject to competition from other species. Barren lakes stocked with trout have produced fish weighing up to five or six pounds in three years (Larkin 1954). In such waters, the introduction of forage fish, especially the redeye shiner, has generally resulted in a decrease in the size of the trout population, reduction in growth rate of small trout and a possible increase in growth rate of large trout (Larkin 1954, Larkin *et al.* 1950, Larkin and Smith 1954).

There are three aspects in the interaction between redeye shiners and rainbow trout: (1) competition for food between the two species; (2) predation of trout on shiners; (3) predation of shiners on trout. The effects of the competition for food are manifest by decline in growth rate of smaller sizes of trout. But considering the fish population and its angling as a whole, predation on shiners by largemouth largely offsets the harmful effects of competition for food. Since the first few years after their introduction, shiners have been eating in increasing quantity by both large and small trout. By 1956 only trout which began their growing season shorter than 17 centimetres seemed more harmed by competition from shiners than compensated by predation upon shiners. Associated with the increased utilization of shiners, there is evidence of increased growth rate of trout in their second and third years. In addition, changes have occurred in the catch of naturally-reared fish that could be construed to indicate higher survival in recent years. The liberations of hatchery-reared fish have helped the fishery to recover from its decline after introduction of shiners. On the average the liberated fish were slightly larger and less variable than the wild fish of comparable age and they grew somewhat faster. It is likely that predation on shiners has resulted in an increase in the numbers of large trout (over 45 centimetres), both wild and hatchery-raised.

In consequence of these changes, angling catch from Paul Lake was roughly equivalent in 1957 to that of the pre-shiner period and the average weight of the fish of the anglers' catch has gradually increased. It is tempting to suggest that liberations of yearling fish could be dispensed with. However, production of trout fry in streams tributary to Paul Lake depends on seasonal weather, and the extent of predation of shiners on young trout may vary. It may be that liberation of 10,000 unmarked fall fingerlings (600 to the pound) in the autumn of 1953 has biased the appraisal of ef-

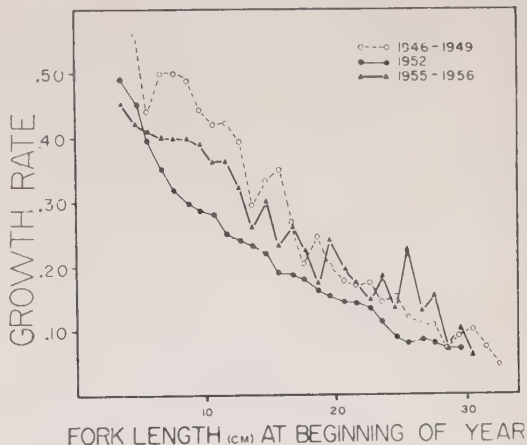


FIGURE 4.—Instantaneous growth rate ($\log_{10}$ fork length at age_{n+1} minus $\log_{10}$ fork length at age_n) in relation to fork length at the beginning of the year for rainbow trout in Paul Lake, before and after the introduction of the redeye shiner. 1946-1949 and 1952 curves are based on those from Larkin, Terpenning and Parker (1957).

fects of shiners on the "wild" population. It seems likely that this single small liberation could not be responsible for a substantial proportion of the observed improvement in growth and survival of unmarked trout. Accordingly, it is concluded that as hatchery yearlings were being liberated, the natural trout population by increased utilization of shiners recovered from the initial deleterious effects of the shiner introduction.

Evidently it had taken the trout several years to "learn" to take shiners as food and there may be still further developments in this direction. From fish taken it appears that trout in Paul Lake under 15 centimetres, as late as 1955-1956, did not eat small shiners or shiner fry, although the two are frequently present in the same place at the same time. Trout of

this size, in captivity, will eat small shiners and shiner fry (Crossman 1959, *in press*).

Future management of the Paul Lake fishery will depend upon the desires of the anglers. Recent progress in the development of fish toxicants could bring the cost of eradicating the shiners to a reasonable level. The decision to treat the lake would be a choice between maintaining the present type of angling, or returning to pre-shiner conditions, *i. e.* a choice between an annual catch—as at present—of 10,000 fish, averaging over 1.25 pounds, with some fish up to 6 pounds, and the possibility, after poisoning, of an annual catch in excess of 15,000 fish, averaging roughly 0.75 pound, with only occasional fish up to 4 pounds.

ACKNOWLEDGEMENTS

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It is the authors' wish to acknowledge the assistance given by the various members of the Fisheries Management Group and the staff of the Kamloops Detachment of the British Columbia Game Branch. Particular acknowledgement is made of the assistance with stomach analysis and age determination of Mr. J. G. Terpenning.

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Survey of Multiple-Use Reservoir Practices in the United States

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ABSTRACT

Information obtained by questionnaire is presented on the multiple-use of water-supply reservoirs. Twenty-eight United States municipalities of over 10,000 population returned completed questionnaires. Of these, 21 municipalities (75 percent) allow recreational use of some kind on 72 reservoirs having a total area of 132,379 acres. Fishing and boating are sanctioned to a certain extent by all 21 agencies, picknicking by 15, sailing by 7, camping and swimming by 2, hunting by 1, and skating by 1.

Permits are required for specific recreational use by half the municipalities permitting such uses. Permit fees range from \$0.35 to \$1.50 per day, \$2.00 to \$3.00 a month and \$3.00 to \$5.00 a year. The maximum fee reported is \$12.50 for a seasonal boating and fishing permit. Regulations and enforcement of them vary. Half the agencies supply sanitary facilities, 81 percent attempt to control trespass and 76 percent have regulations pertaining to "litterbugging."

INTRODUCTION

In 1956 and 1957 Consulting Biologists conducted fishery surveys on two reservoirs, one, 1800 acres in Virginia, the other, 220 acres in Connecticut. The controlling water companies were interested in multiple-use of their reservoirs and requested a plan for multiple-use in conjunction with a fishery management program. To augment the information available on multiple-use of domestic water supplies, it was decided to solicit information from water companies presently engaged in multiple-use programs.

A 5-page questionnaire was formulated that included most aspects of multiple-use programs for domestic water supplies. The recipient of the questionnaire was asked to supply information concerning usage, permits, fees, regulations and enforcement, public relations, fishing, and opinions of water companies about multiple-use.

Questionnaires were forwarded to 110 municipalities. Seventeen were known to permit multiple use of their water supplies because they had been complimented for this progressive approach in the Bulletins of the Sport Fishing Institute. Ninety-three communities in the United States with populations of ten thousand or greater were selected at random. The sample included municipalities in 46 states. Suitable replies were received from 52 municipalities,

a 47.3 percent return. As recipients of detailed questionnaires will frequently only cooperate to the extent of the information immediately available to them, returned questionnaires are often difficult to interpret. This must be considered as a limitation of this study.

Of the 52 municipalities replying, 21 controlled domestic water-supply reservoirs open for multiple-use, 2 municipalities obtained domestic water supplies from TVA reservoirs, 7 communities stated they maintained closed reservoirs, 3 municipalities reported their reservoirs were primarily for power or flood control, 3 cities obtained water from large lakes not considered as reservoirs, and 16 communities controlled no reservoirs. Details concerning multiple-use of reservoirs by the 21 municipalities allowing such are given in the concluding section.

MANAGEMENT OF RESERVOIRS FOR MULTIPLE-USE

The 21 municipalities which reported all, or some, of their reservoirs to be open for multiple-use controlled 112 reservoirs. Of these, 72 reservoirs, with a total surface area of 132,379 acres, were reported open for multiple-use.

Fishing and boating were reported as the two major uses permitted by the controlling agencies, and are sanctioned, at least to a degree, by all reporting agencies that permitted multiple-use. With the exception of several of the reservoirs controlled by the cities of New York and San Francisco, all of the reservoirs

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reported to be open to fishing were also open to boating. Four municipalities permit boating for fishing only.

Picnicking ranks third among the usages permitted by controlling municipalities. Seventy percent favor use of the areas surrounding the reservoirs for this popular indulgence. Three municipalities indicated that they have established special areas for picnicking; two of these agencies selected sites below the reservoir drainage area.

Sailing is permitted by 35 percent of the reporting agencies, all of which control reservoirs of at least 750 acres. The smallest reservoir on which sailing is permitted, Santa Margarita Lake operated by San Luis Obispo County, California, is 750 acres. On this reservoir sailing is restricted to a specific area.

Camping and swimming are permitted by only two of the 21 agencies which returned completed questionnaires. Both of the reservoirs in which swimming is permitted exceed 12,000 acres. The larger of the two reservoirs, 17,242-acre Folsom Lake near Sacramento, California, has sanitary regulations in addition to other regulations governing the usages of the reservoir. The smaller reservoir has few regulations of any kind, and no sanitary regulations. Both of these controlling water departments indicated that they were generally satisfied with all aspects of multiple-use.

Hunting, ice skating, and hiking were each reported once (by different agencies) as being sanctioned uses. Hiking, however, is probably a common usage not generally considered.

Permits and fees for recreational use

There is a great deal of variation by the water companies concerned in the manner of issuing permits. Permits are issued by city managers, water commissioners, boat liverymen, police and/or caretakers at the reservoirs. Of the municipalities with open water supplies, 52 percent require permits.

Agencies having the permit system as part of the management policy of their reservoirs apparently feel that the permits provide them with a means of controlling the use of their waters, the value of which exceeds any additional operating expenses. Through the permit system the identity of the water department and the permitted usage of the reservoir are well established for the permit holder. He is also aware that the penalty for infringements of the regulations governing his use of the reservoir is the revocation of his permit. One

municipality (Charleston, S. C.) was of the opinion, however, that "if permits were required — we would have trouble with those trying to slip in and use the reservoir unwisely." This particular reservoir has never been officially opened for multiple-use, although, aside from posting, no effort has been made to restrict fishing, boating or other activities. It has been the experience of this municipality that the individuals using the reservoir "have done an excellent job of policing the area," and prosecution for trespassing has been completely unnecessary.

Fees for permits or usage exhibited considerable variation, ranging from \$0.35 to \$1.50 per day, \$2.00 to \$3.00 per month, and \$3.00 to \$5.00 per year. Two municipalities indicated fees were slightly higher for non-residents. The basis for establishing fees appears to be directly correlated with the maintenance of the recreational facilities on a self-sustaining level. Consequently, due to the costs of operation, the higher fees are generally associated with the more developed areas. Where boat and outboard motor rentals are provided, fees range from \$1.50 to \$4.00 per day for rowboats and \$6.00 to \$8.00 for boats with outboard motors. The maximum fee of any of the respondent agencies for a seasonal permit for fishing and boating privileges is \$12.50.

Fishing regulations

Although answers pertaining to fisheries management and associated regulations were not provided by all of the co-operating agencies, in every case in which information was supplied, state fishing regulations are in effect. With the exception of one reservoir where no live bait is permitted, no modifications from state regulations are indicated by any of the departments responsible for the reservoirs.

Daily fishing hours are based both on natural daylight hours and horological schedules ranging from sunrise to sunset, and from 5:00 a. m. to 9:00 p. m.

Four reservoirs are open only on certain days of the week. Three others were closed for an entire year for management reasons. These reservoirs are all controlled by San Diego, California.

On one reservoir, fishing is permitted only from boats, not from the banks. On another, anglers are prohibited from trolling within 200 yards of anchored fishing boats.

Fifty percent of the agencies restrict the use of the area in the vicinity of outlets and dams. Distances range from 500 to 6000 feet.

Safety and boating regulations

Half of the agencies reported no safety regulations applying specifically to boating. In view of the meteoric rise in boating in this decade and the efforts of many organizations, in particular the Outboard Boating Club of America, to promote the wise and safe use of boats by the public, we can anticipate that many agencies managing reservoirs will soon feel compelled to adopt at least minimum boating regulations.²

² Subsequent to the presentation of this paper the 86th Congress passed the so-called Bonner Boating bill. This act provides for small boat regulations for safety. It will become effective April 1, 1960.

Minimum boat lengths of 10 to 12 feet are required by four agencies. Four agencies restrict the number of occupants per boat and in one case the number varies according to the size of the boat. Five agencies indicate that they enforce the number of life preservers which must be carried in each boat. Salt Lake City, Utah, permits boating between 5:00 a.m. and 7:00 p.m., with the qualification that at no time when visibility is less than 300 feet shall boats be utilized. Gasoline-powered outboard motors are prohibited by only two agencies, one of which permits the use of electric motors. Three agencies limit the horsepower of outboard motors to 7.5 and 10 horsepower.

Sanitary regulations

With the exception of the sanitary regulations pertaining to "litterbugging," which have been established by 76 percent of the reporting agencies, 50 percent of the agencies indicated no sanitary regulations in force.

Enforcement and offenses

Some form of enforcement of regulations is attempted by all but three of the agencies which cooperated in this survey. Of the agencies which do have an enforcement program in effect, 50 percent of them utilize state fish and game department personnel. In some cases these men are the only individuals authorized for enforcement agents; in other cases they share responsibilities, concentrating on fish and game violations, while municipal police officers enforce other regulations. In the minority situations, personnel are employed specifically

for law enforcement by the controlling agency.

The most common misdemeanors, with which 50 percent of the reporting agencies must contend, are trespassing and usage without the required permit. Two municipalities included swimming as an unauthorized usage with which they are troubled.

Other offenses, listed in the order of occurrence among the agencies cooperating with the survey, are "litterbugging," illegal fires, unsafe boating practices, disregard of state fishing regulations. Forty-three percent of the agencies indicated no specific offenses.

Trespass regulations

Eighty-one percent of the agencies attempt to control trespass by posting, by fencing of their property lines, by police action or by combinations of these control measures. The fact that a combination of posting, fencing, and police is the measure subscribed to by the greatest number of reporting agencies would indicate that, at least in certain cases, such drastic and expensive methods are necessary.

Fisheries management

Only a few of the reservoirs for which reports were received have a fishery management program. Several municipalities are notable exceptions, and at least one of them has carried out a complete reservoir reclamation program followed by restocking.

Creel censuses are being undertaken by several agencies, either through the use of their own personnel or with the assistance of state fishery biologists. In some reservoirs commercial fishermen are employed in an effort to control the rough fish present. One mid-western municipality employs a full-time fishery biologist for rough-fish control and managing the reservoir fishery.

OPINIONS OF OPERATING AGENCIES ON MULTIPLE USE

As a part of the survey questionnaire, a statement was requested from each agency as to their opinion about reservoirs operated for multiple-use.

Of the agencies answering this question, 78 percent are satisfied with the operation of their reservoirs for multiple-use.

Two municipalities are neither for nor against the concept of multiple-use. One water department states that it is opposed to the idea of multiple-use, but indicated that it is about to open a fourth reservoir for more liberal usage than the three already in operation. Only one municipality expressed disappointment over the results of the multiple-use of its two reservoirs.

Interest in the concept of multiple-use for domestic water supply reservoirs is high and growing rapidly, as evidenced by the number (47.3 percent) of respondents to our questionnaire. Many agencies with closed reservoirs replied in order to receive information for use later in establishing a multiple-use program.

Although local conditions differ, and thus influence answers given, variance of opinion indicated that many of the agencies are often not well informed on multiple-use practices for reservoirs. It appears from opinions expressed in the questionnaires that a municipality setting up a multiple-use program should consider the following points that have proven successful elsewhere:

A fishery management program under guidance of a qualified fisheries biologist should be an integral part of any multiple-use reservoir operation. With a planned intelligent approach toward sport-fish management and sport fishing, the most popular recreational usage for most reservoirs, the success of a multiple-use program is almost assured.

Certain minimum fixed facilities should be available. These include convenient access, adequate parking facilities, convenient sanitary facilities that are adequate for protection of public health, and boat launching ramps.

Enforcement of multiple-use regulations should be carried out by personnel employed by the controlling agency. For efficient enforcement, direct identity with the agency governing the use of the reservoir is necessary.

For efficient control of the recreational uses of a reservoir, the permit system is both desirable and practical. Permit fees can be expected to differ in different parts of the country, but, in general, the following are suggested:

	Daily	Seasonal
Grounds-use fee	\$1.00	\$5.00
Boat-use fee	\$0.50	\$2.50

As to number of boats permitted, the following regulations are suggested:

a. Where still fishing only is permitted, four boats for each mile of shore-line open for fishing.

b. Where trolling is practical, in addition to still fishing of marginal areas of the reservoir one fishing boat for each ten acres of water surface.

With local exception, there appears to be no management reason for prohibition of boats for fishing on reservoirs open for multiple-use. When a reservoir is to be opened for fishing boating facilities and access should receive prime consideration. Encouragement of boating can be the answer to problems associated with limited accessible shoreline, maintenance of the shore areas, practical exploitation of the fishery, and satisfaction of the permit holder.

DETAILS ON MULTIPLE USE BY MUNICIPALITIES

1. *Little Rock, Arkansas.* Controls two reservoirs (6400 acres) both of which are open to fishing, boating and picknicking. Activities are limited to the upper areas away from the outlet and/or intake tube. The picnic area is located below the drainage area. State health regulations permit fishing and boating, but the Water Company neither encourages nor prohibits said recreation. No permits are required.

2. *Los Angeles, California.* Controls 27 reservoirs of which two, (6,375 acres) are open to fishing and boating. Fishing and boating facilities are operated by the Los Angeles City Recreation and Parks Department. Creel census data are collected at dock. Fishing is prohibited within 2500 feet of the dam. No permits are required.

3. *Sacramento, California.* Controls one reservoir (17,242 acres) which is open to fishing, boating, swimming, picknicking, and sailing. Year-round fishing is permitted at Folsom Lake in accordance with State angling regulations where recreational facilities are operated by the California State Park Commission. No permits are required. The Water Company is generally satisfied with the operation of the reservoir for multiple-use.

4. *San Diego, California.* Controls ten reservoirs of which eight (7,581 acres) are open to fishing, boating, hunting, picknicking and camping. Fishing days are determined by funds available for operation on a self-sustaining basis, but generally fishing is permitted on Wednesday, Saturday and Sunday. Creel census data are collected and fish catch reports distributed. A daily permit is required for each reservoir. Camps and picnic areas are located below drainage areas. The Water Department is generally satisfied with the operation of the reservoirs for multiple use.

5. *San Francisco, California.* Controls eight reservoirs; four reservoirs (4,055 acres) are open to fishing. Fishing is permitted from the banks only at Hetchy Hetchy and Lake Eleanor Reservoirs. The City Park and Recreation Department operates fishing and boating facilities on Lake Merced Reservoir on a fee basis. Lloyd Reservoir will be open to other forms of recreation. No permits are required. The Water Department indicated that they do not favor multiple-use of reservoirs.

6. *San Luis Obispo, California.* Controls one reservoir (750 acres) which is open to fishing, boating, sailing, picnicking, and hiking. Fishing and boating are limited to the area $\frac{3}{4}$ mile above the outlet. A special area is designated for sailing and picnicking. The Santa Margarita Lake recreation area is operated by San Luis Obispo County. Daily or annual permits are required. The controlling agency is satisfied with the operation of multiple-use.

7. *Auburn, Maine.* Controls one reservoir (260 acres) which is open to fishing, boating, sailing, picnicking and ice skating. Fishing and other activities are prohibited within a 3000-foot radius of the outlet and/or intake tube. No permits are required. The Water District is generally satisfied with the operation of the reservoir for multiple-use.

8. *Baltimore, Maryland.* Controls three reservoirs (8,000 acres) which are open to fishing and picnicking. Fishing is prohibited in the immediate vicinity of outlets and/or intake tubes. Rowboats are permitted for fishermen, but outboard motors are prohibited, except electric outboards not larger than one-fourth horsepower. No permits are required. The Bureau of Water Supply is generally satisfied with the operation of the reservoirs for multiple-use.

9. *Danvers, Massachusetts.* Controls two reservoirs (98 acres) which are entirely open to fishing. Use of rowboats for angling is permitted. A daily permit is required. The Water Department is generally satisfied with the operation of the reservoirs for multiple-use.

10. *New Bedford, Massachusetts.* Controls three reservoirs two of which (3,000 acres) are open to fishing and boating. Sailing is permitted on one of the two reservoirs. Fishing is restricted in the areas near the outlets and/or intake tubes. Annual permits are issued for each reservoir. The Water Department is disappointed with the results of multiple-use.

11. *Meridian, Mississippi.* Controls four reservoirs (10 acres) open to fishing and picnicking; boating is permitted on two of the reservoirs. Fishing is permitted on the entire surface of both reservoirs. No permits are required. The Water Department is generally satisfied with the results of multiple-use.

12. *New York City, New York.* Controls 29 reservoirs, exclusive of lakes on Long Island. Of these, (23,146 acres) are open to fishing and boating. Fishing is restricted within 1000 feet of dams, 500 feet of outlet structures when present, and from edges when so posted. On Long Island lakes fishing is sanctioned, but boating is not allowed. Fishery management programs have been established on most of the reservoirs by the New York State Conservation Department. Annual permits are granted.

13. *Alliance, Ohio.* Controls two reservoirs (400 acres) which are open to fishing, boating and picnicking. Fishing is prohibited near the dams and allways. One reservoir is leased to a private operator who retains all fees for permits and boat rentals. A partial creel census is conducted by the private operator. The second reservoir is open to public fishing and no permits are required. No outboard motors are permitted on either reservoir; rowboats, however, may be utilized. The Water Company is generally satisfied with the results of multiple-use.

14. *Tulsa, Oklahoma.* Controls two reservoirs (829 acres) which are open to fishing, boating and picnicking. Fishing and boating are permitted

over the entire surface of the reservoirs. Creel census data are collected by lake patrolmen and permit clerks. A full-time fisheries biologist is also employed for rough fish netting and management of the Upper and Lower Spavinaw Reservoir fisheries. Daily, monthly and annual permits are issued. The Water Department is generally satisfied with the multiple-use of the reservoirs.

15. *Charleston, South Carolina.* Controls one reservoir, not officially open but receiving multiple-use. The following statement made by the water company explains the situation: "The area around this reservoir is posted, however, no steps have been instituted to prevent fishing, boating, *et cetera*. So far we have found that those who use the reservoir have done an excellent job of policing the area, and we have not had any trouble by not prosecuting anyone trespassing on the reservoir. If permits were required, I am sure we would have trouble with those trying to slip in and use the reservoir unwisely."

16. *Houston, Texas.* Controls one reservoir (12,500 acres) which is open to fishing, boating, sailing, swimming and picnicking. Fishing and other activities are prohibited within a half mile of the intake. No permits are required. The Water Company is generally satisfied with the results of multiple-use.

17. *Wichita Falls, Texas.* Controls two reservoirs (8,400 acres) which are open to fishing, boating, sailing and picnicking. In addition to sport fishing, commercial fishing is permitted for rough fish control. The entire surface acreage of each reservoir is open to fishing.

18. *Salt Lake City, Utah.* Controls four reservoirs of which three reservoirs (2,683 acres) are open to fishing, boating, picnicking and camping. Two storage reservoirs at Big Cottonwood Canyon are open only to fishing. On Deer Creek Reservoir other activities are permitted; however, no fishing is allowed within 6000 feet of the dam. Deer Creek Reservoir also services Provo, Orem and Lindon. Annual permits are issued. The Metropolitan Water District of Salt Lake City is generally satisfied with the multiple-use of the reservoirs.

19. *Charlottesville, Virginia.* Controls three reservoirs (104 acres) which are open to fishing and picnicking. Fishing is permitted only for brood stock fish for introduction into other waters. Daily permits are required; three anglers may fish on one permit. Permits are granted in relation to the size of the pond to be stocked. Boats may be used for fishing, but no boating as such is sanctioned. The Water Department is generally satisfied with the multiple use operation.

20. *Newport News, Virginia.* Controls three reservoirs of which two (650 acres) are open to fishing. Daily permits are issued for each reservoir. The number of anglers is limited to sixty per reservoir. The Water Company maintains thirty rowboats for fishermen on each reservoir. Creel census data are collected at the boat docks by the wardens. Fishing is permitted on the entire reservoir. Fishing is prohibited on Sunday. The Water Company is generally satisfied with the multiple-use operation.

21. *Roanoke, Virginia.* Controls three reservoirs, one of which (13,000 acres) is open to fishing, boating, sailing, and picnicking. Annual permits are issued. Angling is prohibited within 200 feet of the dam. The Water Company is generally satisfied with the operation of the reservoir for multiple-use.

Observations on Growth and Reproduction of the Paddlefish¹

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ABSTRACT

Young-of-the-year paddlefish collected from Fort Gibson Reservoir in 1957 grew to an average total length of 28.4 inches in the first year. A linear regression calculated for the first year of growth suggests that hatching occurred on May 4. Based on a review of the literature and observations made during general fisheries investigations on the reservoir for several years, it is suggested that paddlefish may have a periodicity in sexual maturation.

The paddlefish, *Polyodon spathula*, has been viewed with considerable curiosity by various observers since the time of the earliest American explorers. More recent interest in the species has been directed to its commercial utilization which reached its greatest development during the first decade of the present century. Intensive harvesting by commercial fishing, pollution of streams, and the construction of dams have been considered as contributing factors in the decline of the fishery since that time (Larimore, 1950; Lachner, 1956).

Although the species has never been one of major importance to either commercial or sport fisheries in Oklahoma, it has, however, appeared regularly in the catches from both the Arkansas and Red River systems for several years. Unauthenticated reports from residents in the area indicate that paddlefish were present in Grand River, in northeast Oklahoma, long before it was impounded to create Fort Gibson Reservoir in 1949. The earliest collections from the reservoir revealed that paddlefish were present. As the reservoir filled, these fish spawned to produce what appears to have been a fairly large population. This opinion is based on personal communication with commercial fishermen. The 1951 Oklahoma Legislature enacted a more liberalized commercial fishing law which permitted the use of more efficient gear and broadened marketing opportunities by providing for sales of commercial fishes outside of the state. As a result, the harvest of paddlefish increased immediately, and according to commercial fishermen the size of the population was quickly reduced. De-

partment of Wildlife biologists who worked on the lake in 1954, 1955, and 1956 reported only small and infrequent captures of paddlefish both in their collections and in the commercial catch.

Little information was gathered on the paddlefish in Fort Gibson Lake before 1957 and in that period investigators generally assumed that age and growth could not be reliably interpreted from fin rays. Fortunately, however, an occasional fin ray sample was preserved incidental to other work and these now provide a basis for the interpretation of the history of this population.

Sixteen 2-year-old paddlefish were collected during the summer of 1952 by personnel of the Oklahoma Fishery Research Laboratory and the Oklahoma Biological Survey. Representatives of this same 1950 year-class have been captured by commercial fishermen and fishery workers occasionally since 1952, but there was no evidence of further reproduction until August 16, 1957, when a paddlefish 17.3 inches long was taken. Generous cooperation of Fort Gibson commercial fishermen with fishery workers during that year produced a collection of twenty-three paddlefish of the 1957 year-class (shown in Figure 1). These fish ranged in length from 15.8 to 29.4 inches, and the dates of capture extended from August 16 to December 13, 1957. Commercial fishermen provided further information from 34 additional specimens in 1958. Although information concerning many of these was incomplete, enough fin ray samples were preserved to permit identification of the group as fish of the 1957 year-class.

Microscopic analysis of cross-sections of dentary bones and pectoral fin rays of paddlefish from the 1957 collection revealed no annuli, further proof that these fishes were spawned

¹Contribution No. 71 of the Oklahoma Fisheries Research Laboratory, a cooperative unit of the University of Oklahoma Biological Survey and the Department of Wildlife Conservation.

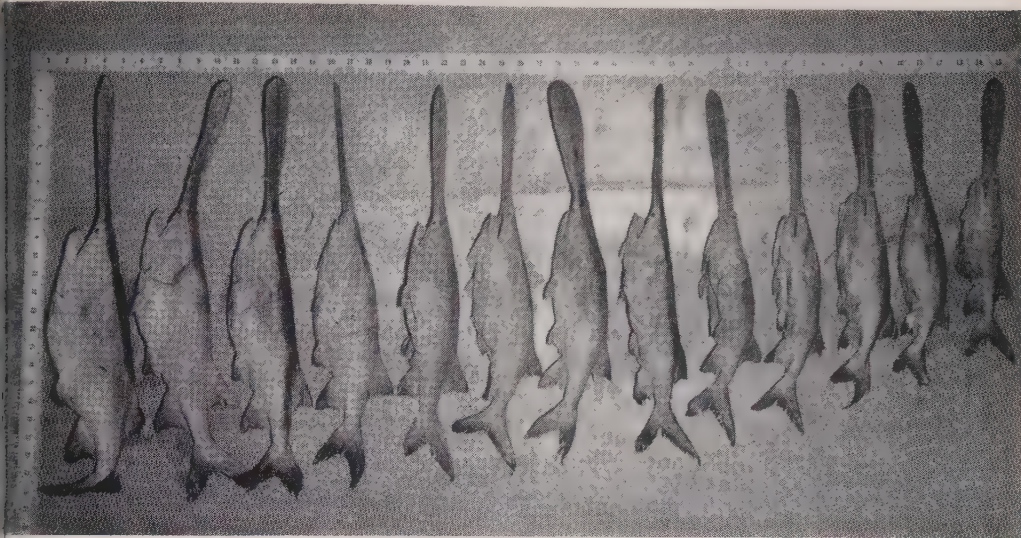


FIGURE 1.—Young-of-the-year paddlefish collected from Fort Gibson Reservoir, Oklahoma, August 16 and October 12, 1957.

1957 was found in a regression equation calculated for their growth through October 12 (Table 1; Figure 2). Extrapolation of the line of regression suggested a probable hatching date of May 4. Since the eight specimens collected in November and December averaged 28.4 inches and since this length intersects the line of regression at October 14 it was assumed that the growing season for the young-of-the-year was from May 4 to October 15, a total of 165 days. The average daily increment of growth was 0.17 inches.

TABLE 1.—Dates of capture, lengths and weights of Fort Gibson Reservoir paddlefish used to calculate a linear regression for the first year of growth, 1957

Date of capture	Total length at capture	Weight ounces
August	16	17.3
	20	15.8
	20	18.3
	22	19.1
	22	21.5
	27	20.6
	29	19.3
	29	21.7
	29	21.7
September	20	23.0
	20	22.1
	23	24.5
	23	24.5
October	6	25.0
	11	27.9
	11	27.2
	12	28.4

The average length (28.4 inches) of the 1957 year-class at the end of their first growing season approximated the length (32 inches) of the 1950 year-class at the end of three years. The accelerated growth of the 1957 year-class during the early period of their growing season occurred when an unusual amount of available food was present in the reservoir. An exceptionally large amount of rain fell during this period and the flood pool elevation was maintained for more than six weeks. The surface area was more than doubled and large areas of vegetation were inundated. Plankton blooms resulted from the increased nutrients provided, especially in the bay areas. We believe that this abundance of plankton organisms, the staple food of paddlefish, accounted for their exceptional growth.

There was very little growth from the middle of October, 1957 to February, 1958 and presumably this condition persisted throughout the winter. Measurements made in November, December, and February indicated that the increase of length was under two inches, probably less than one inch. In the spring of 1958 steady growth was resumed and the average length reached thirty-five inches by July. After the middle of July, and a rise of water level, the growth rate accelerated. In early September the average length was 37.7 inches.

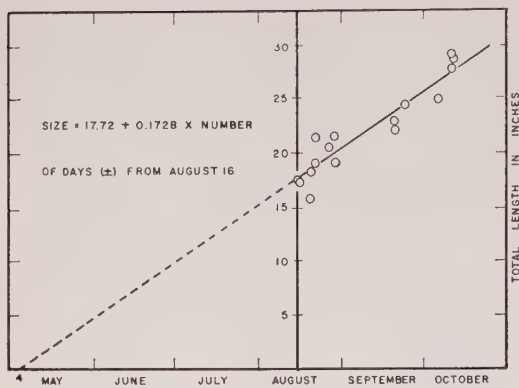


FIGURE 2.—Linear regression of young-of-year paddlefish from Fort Gibson Reservoir, 1957.

Stockard (1907) indicated that paddlefish spawn only in running water. In the spring of 1957 the current in Fort Gibson was strong enough to be noticeable in the main part of the lake. An indication of the relative current velocities in the reservoir can be gained from figures for daily outflow expressed as a percent of the daily storage in acre feet (Table 2). In April and May the average daily displacement of water was 8 and 14 percent respectively. According to Stockard it would be expected that no spawning would occur in the years 1953 through 1956 but could have occurred in 1950, 1951, 1952 and 1958 when strong currents prevailed in May, the hypothetical spawning date in 1957. Spawning occurred in 1950 and 1957 and we have been unable to find individuals of the 1951, 1952 and 1958 year-classes. Our limited observations fail to support a conclusion that the failure could have been due to environmental factors.

TABLE 2.—Amount of daily outflow from Fort Gibson Reservoir expressed as percent of daily storage in acre-feet

Year	March	April	May
1950	13.0	9.0	14.0
1951	13.0	20.0	15.0
1952	3.5	5.0	5.0
1953	0.4	0.7	3.5
1954	2.0	2.0	1.6
1955	0.4	0.4	0.9
1956	2.4	8.0	14.0
1957	Mar. 1-15	Mar. 16-31	Apr. 1-15
1958	8.0	12.0	7.0

Adams (1942) stated that female paddlefish do not mature sexually until they reach an age of about seven or eight years. Paddlefish in Fort Gibson fit this pattern; the adults which spawned in 1957 were themselves spawned in 1950. The lake sturgeon *Acipenser fulvescens* is another fish that matures very slowly. An interesting fact in the light of this similarity of slow maturation and the evolutionary relation of these species, is that the lake sturgeon does not spawn every year after first reaching sexual maturity. There is a periodicity in the sexual maturation and there are different periods between spawns for males and females according to Cuerrier (1949). He further states that males require two years between spawns and the females four or five. Perhaps the paddlefish also has some kind of periodicity. Individuals without ripe gonads that were larger and presumably older than mature fish of the same sex have been reported in the same collection. Larimore reported finding two immature males that were larger than some mature males in one of his collections.

If paddlefish do have a periodicity in their sexual maturation it would explain why they did not spawn in Fort Gibson in 1951, 1952, and 1958 when the currents were presumably similar to those when spawning occurred.

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The Effects of Controlled Spawning and Genetic Selection on the Fish Culture of the Future¹

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ABSTRACT

The role of controlled spawning, genetic selection and physiological research in fish culture is discussed, and emphasis is placed on the importance of the approaches for the future. A review of the literature is given.

Fish culture in the United States must undergo a radical change in the next few years if it is to gain an equal place with other phases of fishery science and fish biology and compute its share to the solution of the ever-growing problem of the world's food needs. The recent work of Pickford and Atz (1957), summarizing the knowledge of fish pituitaries and related endocrines, and of Brown *et al.* (1957) on the physiology and behavior of fishes, provide fish-culturists and other fishery biologists with information with which they can make great progress. American fish culture, as a branch of fishery science, has not discovered or developed many new techniques since its beginning in the middle of the last century. Although much valuable research has been done on nutrition by such workers as Arthur Phillips and colleagues, and on disease control by S. F. Snieszko and others, progress in fish culture has been limited, considering the length of time that it has been practiced. This lack of progress was recognized by Culler (1932), and Wood (1953) stated that American fish culture, including that of the 20th century, has been dominated almost entirely by the practices of artificial propagation. Examination of the published research of fish-culturists certainly substantiates Wood's viewpoint.

Davis (1953) said that the development of fish culture in America has centered primarily around trout and salmon propagation. Undoubtedly, American fish culture was started

for the purpose of propagating the brook trout, *Salvelinus fontinalis*. The American Fisheries Society was founded December 20, 1870, under the name American Fish Culturists' Association (Bower, 1911), by a group of men interested in trout propagation. Certainly the propagation of trout and salmon has dominated fish culture in this country since 1853, when Dr. Theodatus Garlick conducted the first credible experiments on trout culture (Garlick, 1857), but the scope of American fish culture soon broadened to include other species when it became apparent that the yields from certain sport and commercial fisheries were declining. Hatchery propagation was quickly adopted as a panacea for fish population depletion; unfortunately, in spite of numerous published studies to the contrary, this erroneous conclusion is still adhered to by many, and most American hatcheries continue with routine artificial propagation. Davis (1953) might well have added that *the maintenance* of fish culture in America has centered around the production and stocking of large numbers of fish, regardless of the effectiveness in increasing the yield or the contribution to fishery science.

It is most unfortunate that two of the major fields of biology from which fish culture has so much to gain have been neglected—physiology and genetics. Davis (1953), in his book, "Culture and Diseases of Game Fishes," lists 338 references. Judging from the titles, only seven of these concern genetics and two concern physiology directly (33 are on nutrition, some of which may involve considerable physiology). The recent two-volume publication, "The Physiology of Fishes" (Brown *et al.*, 1957), includes parts by 25 authors. Only seven of these writers are Americans, and none are fish-culturists. Gordon (1957), in a paper on physiological genetics of fishes, lists 513

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references. Of these, seven are by fish-culturists, or concern the culture of species other than tropical fishes.

The field of scientific endeavor probably most similar to fish culture, in a general way, is plant and animal husbandry. Here the interest and emphasis are on quantitative and qualitative yield. The great abundance of food produced by the United States attests the effectiveness of the research in these phases of agriculture. Compare the modern beef cattle with those of 1858, or the yield of a field of wheat, corn, or oats, or an orchard of apples or peaches with that of 100 years ago. Much of the difference is due to research in the genetics and physiology of the organisms involved.

It is surprising that fish-culturists have not experimented more with selective breeding of the species commonly propagated in American hatcheries, since it is obvious that so much is to be gained from such research. Undoubtedly, two of the principal deterring factors are lack of proper facilities (Wright, 1951-52) and inadequately trained personnel at a large percentage of state and federal hatcheries. Actually such experiments would not necessarily require intensive education and training in genetics by those who conduct them. Smith (1924) credited the Japanese with developing gold-colored goldfish from the natural-colored, wild populations as early as 1500 A.D.

During the second decade of this twentieth century simple Mendelian inheritance in fishes was demonstrated by Ishikawa (1913), Toyama (1916), and Ishihara (1917). This discovery was a valuable tool for the fish-culturist, although it was not apt to come to their attention because of the inaccessibility of the journals in which these papers were published. From 1920 to 1930 the literature contained many papers concerned with fish genetics. Many of these were by American workers (geneticists, not fish biologists), including a good summary by Goodrich (1929). Most of them dealt with such genera as *Lebistes*, *Oryzias*, *Xiphophorus*, *Platypoecilus*, and *Fundulus*.

Embody and Hayford (1925) recognized the potentialities of selective breeding of fish for producing desired traits, other than ornamental color and shape, because they were aware of "the astonishing results obtained by breeders of domestic animals and plants." They were able, by selective breeding, to increase the resistance of brook trout to certain diseases, and at the same time, to increase the growth rate of the experimental fish. These experiments

were carried further (Hayford and Embury 1930) with still greater growth and much greater egg production as important results. Davis (1931) reported that the spawning period of brook trout was shortened by selective breeding, and enumerated several improvements in trout that could be expected from further similar experiments.

Later published research on selective breeding of fish is scarce. This field of endeavor was not accelerated as it should have been. Lewis (1944) reported increased egg production and earlier maturity due to selective breeding. Millenbach (1950) found that although age at maturity could be lowered, egg production and growth rate decreased as a result of experimental selective breeding. Carl (1953), and Ratledge and Cornell (1953) reported on attempts to breed a nonmigratory strain of rainbow trout. Wolf (1954) described experiments, with positive results, to develop disease resistant strains of trout. Alkhu (1956) indicated that the Russians have experimented to improve the breed of carp. Donaldson and Olson (1957) discussed breeding experiments conducted on rainbow trout for 23 years which have improved growth rate at maturity, resistance to disease, tolerance to warm water, and egg production. In addition to these, several other papers have been published on experimental hybridization of both warm and cold-water fishes in many parts of the country.

The research on the physiology of fish that is of great significance to fish culture is that which concerns the use of hormones to precipitate spawning. This research was apparently started in Brazil about 1932 by Dolpho von Ihering and D. A. Cardoso (von Ihering and Wright, 1935; von Ihering, 1935) who used extracts of the hypophysis of fish to induce spawning in other fish. Variations of this technique have been tried on several species of the warm and cold-water fishes often propagated in hatcheries, e.g., Ball and Bacon (1954); Burrows, Palmer, and Newman (1952); Chaudhuri and Alikunhi (1957); Fontenele (1955); Hasler, Meyer, and Fiedler (1939, 1940); Migata *et al.* (1952); Moore and Thune (1957); Palmer *et al.* (1954); and Ramaswami and Hasler (1955).

In 1955, when we started research (a Saltwater-Kennedy project) on the propagation requirements of the channel catfish, *Ictalurus punctatus*, we tried to induce spawning by the injection of pituitary hormones obtained from

(*Cyprinus carpio*) and several other rough fish. Results were sufficiently successful to lead us to concentrate on this aspect of the full research. By the spring of 1957 we were able to spawn channel catfish in aquaria in the hatchery holding house (Clemens and Reid, 1957) producing almost 500,000 fry (Sned, 1958).

This year, Sneed and Dr. Howard P. Clemens successfully tested human chorionic gonadotropin that can be purchased from drug companies. Excellent results were obtained in inducing spawning with this hormone, and approximately 700,000 channel catfish fry were produced from fish spawned in aquaria, where the previous maximum fry production by conventional methods at this station, before the beginning of the research program, was 100,000.

We have successfully induced spawning in warm-water fishes by pituitary injections, flathead catfish (*Pylodictis olivarius*), rock bass (*Ambloplites chrysops*), rock bass (*Ambloplites rupestris*), white crappie (*Pomoxis annularis*), and several cyprinids, and intend to treat them with the mammalian hormone for the same purpose. The results of this research have been reported in several papers now in press and in a manuscript. We feel that the use of a mammalian hormone, which is effective and easily obtained, for inducing spawning in channel catfish and other warm-water fishes, is highly significant. Although carp pituitaries are available, an adequate source is rarely certain, and considerable cost and time consuming is involved in collecting them.

With the foregoing facts in mind it is stimulating and revealing to theorize on the future of fish culture. Although we are aware of all attempts to induce spawning by hormone injection have not met with success (Burton, Palmer, and Newman, 1952; Palmer et al., 1954) we feel that knowledge of the chemistry of hormones and the physiology of fishes is advancing so rapidly that within the next few years spawning of almost all fish can be induced by hormone injections and techniques should revolutionize fish cul-

ture. Among those problems that confront the aquaculturist who attempts research on selective breeding of fish are: (1) variation in spawning time; (2) peculiarities of spawning behavior; (3) peculiarities in environmental requirements for spawning, particularly space, visual and tactile stimuli; and, (4) uncer-

tainty of regular spawning. Such problems should all be solved by the proper use of hormones. Our research with the channel catfish has virtually solved these problems as far as the culture of this species is concerned. (1) Channel catfish ripen from May through mid-July. Hormone injections precipitate spawning in ripe females in 16 to 60 hours, depending on the physiological condition of the recipient fish, the dosage of the hormone used, the water temperature, and other environmental factors that affect the response of the female. Our work and that of others (Robertson and Rinfret, 1957) suggest that techniques can be developed that will mature the gonads and permit earlier seasonal spawning. (2) Channel catfish normally spawn in depressions in the lake or stream bottom, or in holes in the bank, hollow logs, kegs, etc. Injected fish spawned in aquaria as small as six-gallon capacity; control fish did not spawn in aquaria. (3) Previously channel catfish propagation required spawning pens and large ponds (Mobley 1931; Toole, 1951; etc.). (4) Many hatchery superintendents reported (*correspondence*) that a large percentage of channel catfish females do not spawn in some spawning seasons. Our research suggests, barring accidents or faulty procedure, that practically all well-developed females can be spawned by the use of hormones. Thus, selective breeding experiments are made more practicable when preceded or accompanied by proper hormone injection.

Among the goals of any good hatchery are: (1) greater efficiency and economy of operation; (2) greater egg production with a greater production of fish; (3) greater resistance to disease and parasites; (4) faster growth; (5) earlier sexual maturity. It should be obvious, in light of the previous discussion, how physiological and genetical research will help attain the last three goals. They have already been achieved to some extent for trout, but much more research is needed, especially on other species.

Greater efficiency and economy should result from greater production, less space requirement, fewer brood stock, less mortality and shorter periods of maintaining those fish produced. Selective breeding and controlled spawning can make realities of these desirable but theoretical conditions.

Greater production would be enhanced by higher fecundity, lower mortality, etc. It is also logical to suppose that the combination of hormone injections and genetical selection will

bring about year-around production of any given species, especially if light and temperature can be controlled. At certain hatcheries, programs of winter and summer production could be developed, with one species or group of species being propagated during one season (e.g., trout), and another species or group during the alternate season (e.g., smallmouth or largemouth bass and channel catfish).

By working closely with those concerned directly with fishery management, the fish-culturist could develop strains of a particular species that would be tolerant to environmental conditions which they do not normally tolerate. In this way, unproductive waters could be made productive by being stocked with fish bred for the habitats which such waters provide. The ranges of the walleye, the muskellunge, the northern pike, and many other popular game and food species could thus be increased. Certain euryhaline species could be bred for permanent habitation in fresh water. The applications to management are numerous and exciting.

Other probabilities are that one warm-water hatchery will propagate only one, or possibly two species throughout the year, and the other hatcheries in the region will concentrate on one or two additional species, thus greatly increasing "regional production." Certain hatcheries could become "propagation hatcheries," producing eggs or sac-fry, and other nearby hatcheries would be "rearing hatcheries," raising the fish to the desired size for stocking, as is now practiced in the case of some trout and salmon hatcheries.

All this will of course modify the facilities and personnel of hatcheries. Artificial propagation (stripping and dry fertilizing) will become more prevalent and require its special facilities. Tanks, vats, troughs, and raceways will be used more in place of ponds. Fish culture will tend to move inside where environmental factors can be controlled. Hatchery personnel will have to be better educated and better trained in order to use and understand the tools of physiology and genetics, and thus the services of universities will be more extensively used by the federal and state governments and private enterprises as special training programs become necessary. There is also a need in this field for additional training schools operated by personnel of universities and federal and state agencies concerned with fish and game in particular areas where both

the problems and facilities for solving the problems already exist.

Finally, we should not overlook the consequences of all this advancement in fish culture in terms of increased food production. Fish farming will become a "sure thing" with large and consistent yields. By 2058 the increased yield of fish produced as a result of research and advancement in fish culture could be of great importance to the probable crowded population of North America, just as the fish produced by fish farming in Europe and Asia in 1958 is of great importance to a large percentage of the population of those countries.

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Effects of Temperature upon the Formation of Vertebrae and Fin Rays in Young Chinook Salmon

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ABSTRACT

Experiments in each of three successive years were designed to observe the effect of temperature upon chinook salmon, *Oncorhynchus tshawytsch* (Walbaum), during the period from the egg to the fingerling stage. Experimental temperatures ranged from 34° F. to 74° F. but there were no survivals to the stage where vertebrae or fin rays could be counted for lots reared at temperatures below 39° F. or above 62° F.

For these experiments the average number of vertebrae per lot was less for lots reared at temperatures in the middle portion of the 39° F. to 62° F. range than for lots reared at either extreme of the range. The same effect was observed in regard to the number of individuals with abnormal vertebrae, but the opposite effect was observed in regard to the numbers of rays in the anal and dorsal fins. The average numbers of vertebrae in the lots from the Sacramento River (California) and the three Washington rivers—Skagit, Green and Entiat—and reared at the same temperature (56° F.) were respectively $66.39 \pm .047$, $68.36 \pm .052$, $69.57 \pm .23$ and $71.73 \pm .031$. For all lots the range in number of vertebrae was 63 to 78.

INTRODUCTION

As early as 1862, differences in the number of vertebrae for fish of the same species from different geographical areas had been associated with differences in temperature. Gabriel (1944) wrote as follows:

Following the early generalizations of Günther (1862) and Gill (1863) that the number of vertebrae is higher in genera of fishes inhabiting northern latitudes than in related fishes from tropical regions, Jordan (1891) prepared a "law" setting forth an inverse relationship between the vertebrae number of a species and the water temperature prevailing in its geographic range.

About the same time that Jordan's "law" was proposed the use of meristic characters, particularly vertebrae, became an accepted method for defining races as a result of Heincke's investigations on the herring (Heincke, 1898). When Heincke found that the difference in the average vertebral count of two populations of herring was statistically significant the populations were identified as races. From Jordan's "law" and Heincke's work the idea developed that the differences in the count of meristic characters that exist between races of fish could result from the effect of temperature.

A great many racial studies based upon field observations confirm Jordan's "law". Included in the list of such studies is the work of Hubbs (1925), Rounsefell and Dahlgren (1932), Tester (1938) and McHugh (1954)

on the herring; of Schmidt (1930) on the cod; of Weisel (1955) on the cyprinids; and of Mottley (1937) on the trout.

Laboratory experiments have an advantage over field experiments in that the information about the factors that are responsible for variation in meristic characters, *e. g.*, counts of meristic characters of the parents, temperature history, etc. can be obtained for individual fish rather than only for groups of fish. Laboratory experiments have been few in number. Tåning (1952) reviewed these experiments which included the work of Schmidt, C. McC. Mottley, A. V. Tåning, M. L. Gabriel, M. J. Heuts, and A. Dannevig. To this list Marckmann (1954) and Lindsey (1954) should be added. Conclusions from these experiments in regard to the effect of environmental factors upon the formation of vertebrae or fin rays are as follows: (1) either low oxygen or high CO₂ pressure increases the number of vertebrae; (2) pH in the range from 6.4 to 7.8, egg size, fry size, or time of hatching, have no effect on vertebral number; and (3) salinity and temperature modify both vertebral and fin ray number.

The results of laboratory experiments to determine the effect of temperature on the modification of vertebral number have not been consistent. Schmidt (1921), Tåning (1950) and Lindsey (1954) have shown that fewer vertebrae are formed by fish reared at intermediate temperatures than by fish reared at

her high or low temperatures. By contrast the results of experiments by Gabriel (1944) and Dannevig (1950) show an inverse relationship between number of vertebrae and temperature for the entire temperature range. In other words, the results of Gabriel and Dannevig are in general agreement with Schmidt and Tåning and Lindsey at low temperatures but not at high temperatures.

For the Pacific salmon, laboratory experiments to determine the effect of temperature on the formation of vertebrae are unknown. There have been experiments to determine the effects of temperature. For chinook salmon, Brett (1952) has determined the temperature tolerance for fingerlings; Donaldson (1955) has studied the effect of high temperatures upon the survival of the eggs and Olson and Foster (1957) have reported the temperature tolerance for eggs and young from the Columbia River near the Hand Project.

The experiment reported here was designed to obtain information about the relationship of temperature to the formation of meristic characters in young chinook salmon and was part of a larger experiment for which other objectives were to determine the effects of temperature upon: (1) the occurrence of morphological abnormalities; (2) the rate of embryological development; (3) the growth of eggs and fingerlings; and (4) survival. The report of the complete experiment has been prepared as a graduate thesis (Seymour, 1956).

PLAN OF EXPERIMENTS

The experiments were conducted at the School of Fisheries, University of Washington, each of three successive years—1951-52, 1952-53, and 1953-54. These experiments were conducted in four principal aspects: (1) water temperature pattern; (2) type of water; (3) initial stock from which the egg lots were obtained; and (4) number of pairs of parents per lot.

The experiments were designed to follow either one of two temperature patterns: temperatures were either maintained at a constant level or were altered throughout the experiment in a manner similar to that which occurs under natural conditions. Ideally, the experimental temperatures should be those to which the fish are exposed in nature, for it is possible that normal development of eggs and fry is adjusted to the natural water temperature pattern.

In nature chinook salmon spawn during late summer or fall at a time when water temperatures are declining. Jordan and Evermann (1896) wrote, " - - it spawns in August and early September when the water has reached a temperature of about 54° F." At the time of spawning the eggs are deposited in nests in the stream bottoms. Upon hatching, the fry being negatively phototropic, work their way deeper into the stream bottom and do not emerge from the gravel until the yolk is nearly absorbed and the fry needs to seek food. The water temperature at the time of hatching is near the lowest level of the annual temperature cycle but by the time of emergence, water temperatures are rising. The annual water-temperature cycle in the School of Fisheries hatchery reaches a low near 40° F. in February and a high near 70° F. in August. This is typical of the temperature cycles in other Pacific Coast salmon streams except that the extreme temperatures may be greater.

In deciding whether to use a constant or an altered temperature pattern, consideration was given to the fact that the period during which temperature can affect the number of vertebrae that are formed is short. For *Salmo trutta trutta* the plastic period was just prior to the eyed egg stage and lasted approximately two days at 10°C., or 1/20 the time required for the eggs to hatch (Tåning, 1952). As the plastic period for chinook salmon was not known, the decision was made to maintain a constant temperature pattern for the first experiment.

Experiments I and II

In the first experiment eight lots were reared at constant temperatures in water from the city main, and all eggs were taken from one pair of chinook salmon of the Green River race. The experiment was initiated November 15, 1951, and concluded October 2, 1952.

The eggs were divided into eight experimental and four control lots of about 560 eggs per lot. The eight experimental lots were reared at temperatures of 34°, 40°, 45°, 50°, 55°, 60°, 62½° or 65° F. A maximum temperature of 65° F. was chosen because in an earlier trial experiment all eggs at a constant temperature of 73° F. and 67° F. had died. The control lots were reared at the water temperature as received from the city main, which was 53° F. at the beginning of the experiment and 41° F., the low for the year, at time of hatching. Graphs of the tem-

perature history of the lots of the first experiment are shown in Figure 1.

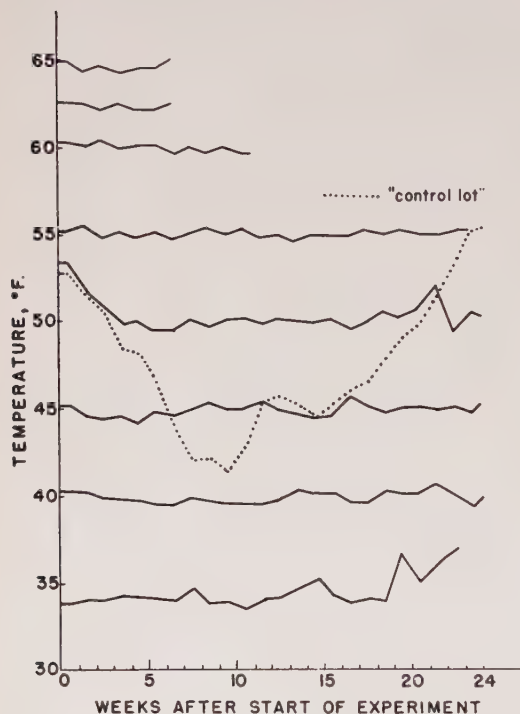


FIGURE 1.—Water temperatures for the eight experimental and four "control" lots of the chinook salmon in Experiment I.

The second experiment duplicated the first experiment except for a slight alteration in the selection of temperatures. The 34° and 40° F. lots were omitted and 57½° and 67½° F. lots were added. As the second experiment was started on October 13, 1952, a month earlier in the year than the first experiment, water temperature of the control lots was 11° F. higher than the water temperature of the control lots of the first experiment.

Experiment II was concluded unexpectedly on December 28 by an accident that caused a great increase in mortalities in all lots. The cause of death was the high pH of the water supply created by a change of charcoal in the filter system. The details of this accident have been reported by Seymour and Donaldson (1953). At the time of the accident the lot at the lowest temperature had just completed hatching. The experiment was concluded at this time, as there was 100 per cent mortality

in some lots and injury of unknown extent to those that did survive.

Experiment III

The third experiment differed from the first two experiments in regard to temperature pattern, source of eggs, number of parent fish and water supply.

Whereas the experimental lots were held at constant temperature in Experiments I and II, the temperatures were altered in accordance with a pre-selected pattern during the third experiment. A pattern was selected to resemble the temperatures that occur in nature and was based upon the average of daily water temperatures in the hatchery of the School of Fisheries for the three-year period previous to the experiment. For the five experimental lots the starting temperatures were 45°, 50°, 55°, 60° and 65° F. After the start of the experiment the water temperature was reduced 1° F. every five days to a low of 34° F. at which temperature the eggs were held for twenty days and after which the temperature was increased at the rate of 1° F. per five days. For the control lots, the water temperature was practically constant (54° F.), the water for the third experiment came from a well rather than from the city main as in the first two experiments. The temperature pattern for the lots of Experiment III is shown in Figure 2.

In order to evaluate phenotypical and genotypical variation in the number of vertebrae in eggs for the third temperature experiment were obtained from four stocks of chinook salmon. An effort was made to obtain eggs from stocks that were distributed throughout the entire geographical range of the species, but eggs were not available from Alaska. Eggs were obtained from stocks in four rivers in Washington and California: the Skagit, in northwestern Washington, on September 11, 1953; the Entiat, a tributary to the Columbia River, in eastern Washington, on October 8; the Sacramento, in California, on October 30; and the Green, near Seattle, on October 30, and from which eggs for Experiments I and II were obtained.

Eggs for the Skagit lots were obtained from three females and were fertilized by two males; for the Sacramento lots, four females and four males were used; and for the Entiat and Green River lots, only one pair was used for each lot, the same number as in Experiments I and II.

Also in the third experiment well water replaced city water. The well water contained considerable amount of organic material which resulted in the accumulation of slime, molds and algae on the eggs and in the tanks and troughs. This necessitated more handling of the eggs than was desirable and may have been related to the unusually high mortality of egg lots in Experiment III.

METHODS

Usual hatchery practices for handling eggs were followed except that special care was taken to avoid undue handling of the eggs. A glass-rod tray was designed so that the eggs could be kept in order and examined individually, if necessary, without disturbing other eggs. The eggs of Experiments I and II were undisturbed during embryological development; however, in Experiment III an accumulation of organic debris and mud made it necessary to agitate the eggs gently about once a week to prevent smothering.

Temperatures were recorded on a 7-day circular thermogram from which average tem-

peratures were calculated by either an arithmetical or graphical method. The accuracy of the estimates of the average temperature is influenced by the reliability of the thermometer (0.1° F.), the accuracy of the thermograms (0.2° F.), the temperature differential at various positions on the egg tray (0.2° F.) and the method of calculation. From all sources the total error in the calculated average temperature can be reasonably assumed to be less than 0.5° F.

The counts of vertebrae and fin rays were made from radiographs or of stained specimens. For the young fry the staining method was more effective but for fish of late fry or fingerling stage either method produced excellent results. However, the radiographic method (Bonham and Bayliff, 1953) was preferred because the radiographs provided a permanent record that could be rechecked easily and the method was faster.

Oxygen analysis followed the basic Winkler Method as outlined by Ellis, Westfall and Ellis (1948). With one exception the dissolved oxygen content in all samples was greater than 70 per cent of saturation and in most cases

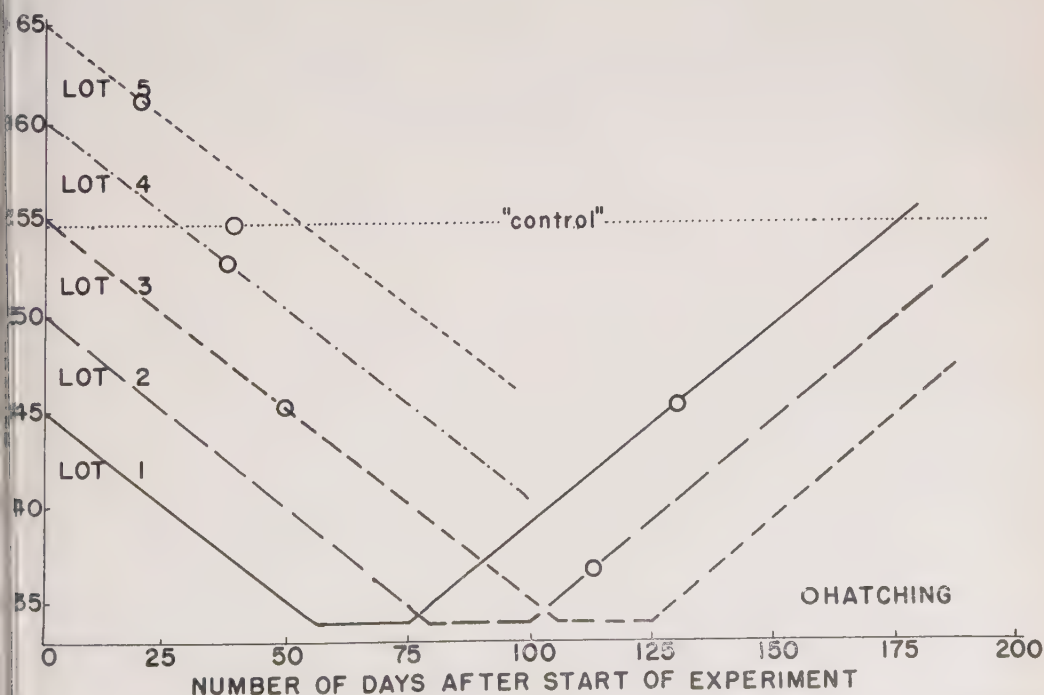


FIGURE 2. Water temperatures from the beginning of the experiment to the fingerling stage of chinook salmon for the lots of Experiment III.

greater than 90 per cent. Differences at various positions within a tank or trough were not significant. In Experiment III two sublots were in water of low oxygen content, 3.0 p.p.m., for the early part of their embryological development, and for this reason the data from the two sublots has been considered separately.

Environmental factors other than oxygen were considered to be of no or equal effect to all lots. Details concerning materials, methods and environmental conditions are given in the thesis (Seymour, 1956).

RESULTS

Vertebrae

The number of vertebrae was determined by counting the centra between the basioccipital and the urostyle.¹

The vertebrae as seen in a radiograph are shown in Figure 3. When abnormal vertebrae

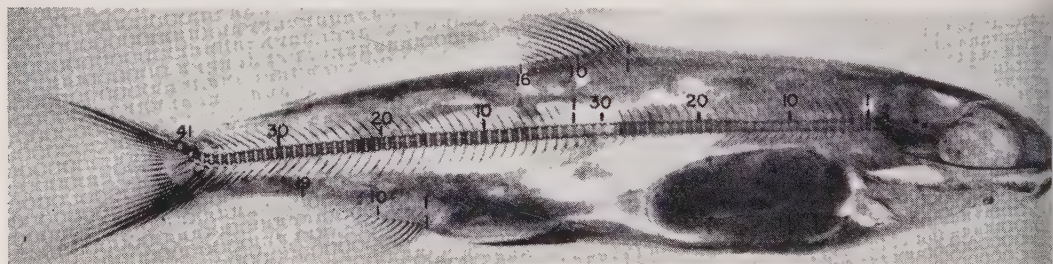


FIGURE 3.—Radiograph of a chinook salmon fingerling showing vertebrae, 73 (32 abdominal + caudal); anal rays, 19; and dorsal rays, 16. ($\times 3\frac{1}{4}$) [The first caudal vertebra of a salmon is defined as the vertebra with a "sudden increase in length of the haemal spine." The first haemal spine is indeterminate as it is a minute process which gradually becomes longer on succeeding vertebrae (Clothier 1950).]

were encountered, the number of vertebrae was determined by counting the arch elements, but when both the centra and arch elements were in doubt, no count was made. The latter event occurred only rarely. In the caudal area the centrum was counted as one if separation was not complete.

The vertebral counts and temperature of lots from Experiments I and II are recorded in Table 1 and shown graphically in Figure 4. The U-shaped curve of Figure 4 shows that the average number of vertebrae per lot in-

creased at both high and low temperatures. The data for Experiment II are limited to the high temperatures because of the accident that necessitated an early closing of the experiment, but substantiate the Experiment I data for the high temperatures.

For Experiment III the record of vertebral counts is tabulated in Table 2. These data do not show the same increase in the number of vertebrae at high and low temperatures as was seen in the Experiment I data; on the other hand, there is no decrease in vertebral number at high temperatures such as was found by Gabriel (1944) and Dannevig (1950). The temperatures given in Table 2 are the average values during the incubation period but more properly should represent the temperatures at the time the number of vertebrae is determined, i. e., the plastic period. Tåning (1952) has shown that the plastic period for determination of the number of vertebrae in *Salmo trutta trutta* is from 145 to 165 D° (day de-

grees with temperature in degrees centigrade) for which the total incubation period is 400 D. Using temperature values calculated on the basis that the plastic period for chinook salmon is the same as for *Salmo trutta trutta* the curves expressing the relationship between temperature and the number of vertebrae in Experiment III were shifted to the right but changed only slightly in shape.

An observation that was not a part of the planned experiment provides some information about the plastic period for chinook salmon. In Experiment III the data from Lot E (Entiat River) 6 suggest that the plastic period begins before the 21st day for eggs that hatch in 46 days. Lot E 6 was uninter-

¹ Vladikov (1954) states: "Urostyle is the posterior terminal segment which follows the last undoubted centrum. In Salmonidae the urostyle remains non-ossified."

TABLE 1.—*Vertebral counts of Green River chinook salmon reared at constant and city water temperatures.*

Experiment	Lot	Temperature °F.	Number of fish with vertebral counts indicated in heading						Lot statistics		
			66	67	68	69	70	71	x	n	s _x
I	2	39.8			23	135	59	1	69.17	218	.0410
	3	44.7		1	109	84	2		68.44	196	.0377
	5	50.6		2	175	79			68.30	256	.0298
	6	55.1		1	59	44			68.41	104	.0504
	7	60.2		1	2	6	3	1	69.08	13	.288
	4	47.4*		7	196	75			68.24	278	.0291
	8	47.0*		12	249	103	1		68.25	365	.0268
II	3	54.6	7	90	72	6			67.44	175	.0476
	5	57.8	2	63	117	18			67.76	200	.0440
	4	58.5*	2	71	93	22			67.72	188	.0495

city water

nally incubated in water of low oxygen content for the first 21 days, after which the oxygen level was normal. Since it is known that low oxygen tension in water increases slightly the number of vertebrae in sea trout (Täning, 1952) and the average number of vertebrae per fish in Lot E 6 was greater by more than in any other Entiat lot at either higher or lower temperatures, it is assumed that the plastic period for the formation of vertebrae in Lot E 6 began before the 21st day of incubation.

From the Experiment III data in Table 2 the great variability in number of vertebrae between stocks can be seen. The racial averages of the lots for all temperatures are about 66 for Sacramento, 68 for Skagit, 69 for Green River, and 72 for Entiat. By Ginsburg's (1938) definition the difference between the Sacramento and Entiat races is equivalent to a species difference since the overlap in the vertebral counts between the two races is less than 10 percent.

The range of vertebral counts of individual fish for the three experiments was 63 to 77, including lot E 6 and Sk 6 in Experiment I, and was greater than the range of similar series given in the literature. Jordan and Seale (1896) report a value of 66 per cent; Foerster and Pritchard (1935), for British Columbia chinook salmon, report 69.5 ± 0.14; and from Townsend (1944) the average value was 67.4.

In the third experiment two lots, E 6 and Sk 6, were unintentionally reared during part of the egg stage in water of low oxygen con-

For lot E 6 the average number of vertebrae was 2.62 greater than for other lots in the E (Entiat) series and for Sk 6 the aver-

age was 1.73 greater than for other lots in the Sk (Skagit) series. Since there were no other obvious differences between E 6, Sk 6 and similar lots, the exposure of the eggs to water of low oxygen content is assumed to have caused the increase in the number of vertebrae. The oxygen content of the water during the early part of the egg stage for lots E 6 and Sk 6 was 3.0 p.p.m. which is 28 percent saturation at 54° F. The increase in vertebrae of 1.7 and 2.6 is even greater than might have been expected from the observations of Täning (1952), who found that in the range from 58 to 98 percent oxygen saturation the increase

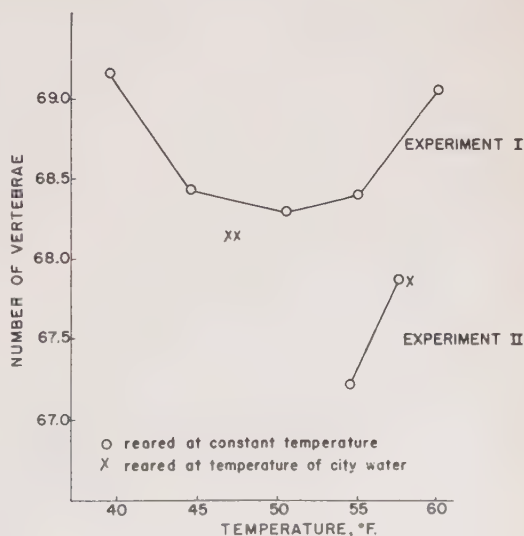


FIGURE 4.—Average number of vertebrae and the temperature for lots of Experiments I and II.

in the average number of vertebrae of the sea trout was about 0.1 for each 10 percent decrease in oxygen saturation (see Fig. 7, *op. cit.*)

In counting vertebrae the number of abnormal vertebrae also was recorded. All vertebrae with modifications of the centrum were arbitrarily classified as abnormal, but vertebrae with modifications and duplications of the neural and haemal arches and spines were not placed in this category. The most common type of abnormality was that of fusion. Spiral suturing was observed and occasionally the centra were heavily ossified.

For Experiments I and II the percent of chinook salmon with abnormal vertebrae was 8.7 at 39.8° F., 8.2 at 60.2° F. and averaged 4.0 percent at eight intermediate points (see Fig. 5). The same trend for Experiment III is also indicated by the graph shown in the lower part of Figure 5. The increase in the number of abnormal vertebrae at either high or low temperatures was similar to the effect of temperature upon the total number of vertebrae.

There were two regions of the vertebral column in which abnormalities appeared most frequently. Thirty-nine percent of the abnormalities were found in the last 10 vertebrae, which include the area in which the vertebral column turns upward, and 34 percent were between the 10th and 20th abdominal vertebrae. Temperature and the area of occurrence of abnormal vertebrae did not appear to be related.

When the average numbers of vertebrae of the fish in lots of Experiments I and II (Table 1) are compared with the numbers of

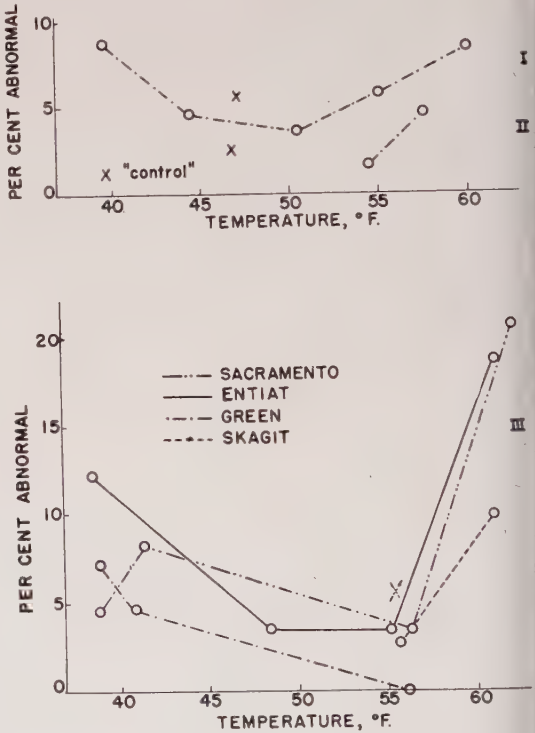


FIGURE 5.—Temperature and percent of chinook salmon with abnormal vertebrae for lots of Experiments I, II and III.

TABLE 2.—Vertebral counts of Sacramento, Skagit, Green and Entiat River chinook salmon of Experiment II.

Lot	Temperature		Number of fish with vertebral counts indicated in heading																Lot statistics		
	°F.		63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	x	n	s _x
Sa	1	39.0		5	16	44	18	1											65.93	84	.091
	2	41.6	1		7	51	67	39	8	6	3								66.09	182	.089
	4	56.5		1	23	117	98	13											66.39	252	.047
	5	62.2			7	11	14	1	1										66.35	34	.168
	6	55.5*		16	108	133	36	3											65.67	296	.046
Sk	4	55.9				1	25	104	81	13									68.36	224	.051
	5	61.3				3	20	30	15	3									67.93	71	.101
	6**	54.7*					5	6	18	33	24	15							70.09	101	.130
G	1	39.0						4	26	46	23								69.89	99	.087
	2	41.6				2	1		5	9	4								69.43	21	.320
	4	56.3				2			12	10	5	1							69.57	30	.231
	6	55.4*		1	1	1	14	40	25	2									69.07	84	.104
E	1	38.8							10	39	29	4							71.33	82	.081
	3	48.4							5	19	6								71.03	30	.351
	4	55.2							3	149	247	29		3	1				71.73	432	.031
	5	61.3							5	65	114	56	11	2		3	1		72.10	257	.069
	6**	55.2							2	8	13	26	107	137		70	28	1	74.72	392	.060

*At constant temperature, 54-56° F.
**Water of low oxygen content during incubation

vertebrae of the parents, the average counts are about one vertebra greater in the offspring than in the parents. If this difference is due to some factor in the environment, it is assumed that the effect is equal for all lots.

In summary, the following observations on the effect of temperature upon the formation of vertebrae in chinook salmon have been made: (1) in comparing lots reared at various temperatures, the average number of vertebrae is less for lots reared in the range from 45° to 55° F. than for lots reared at either higher or lower temperatures; (2) the average number of vertebrae was about 66 for the progeny from the Sacramento stock, 68 for the Skagit, 69 for the Green and 72 for the Entiat; (3) above 60° and below 40° F. the number of individuals with abnormal vertebrae increased; (4) low oxygen content of water during incubation increased the number of vertebrae.

Dorsal rays

In counting the rays of the dorsal fin all rays were included. This is not common practice when counting dorsal rays for the purpose of identifying or classifying fishes because the short, anterior rays are difficult to identify without special preparation. However, in this experiment all specimens were either stained or radiographed. As a result all rays of the dorsal fin were easily identified and there was no reason for not counting all rays.

For purposes of classification, usually the anterior rays that are less than one-half the length of the longest dorsal ray are not counted and, therefore, the counts of dorsal rays of chinook salmon that are given in the literature are less than the counts reported for this experiment. Jordan and Evermann (1896) list 11 dorsal rays for the species; Foerster and Pritchard (1935), 11 to 14; Clemens and

TABLE 3.—Numbers of dorsal rays for chinook salmon in Experiments I, II and III

Experiment	Lot	Temperature °F.	Number of fish with dorsal ray counts indicated in heading						Lot statistics		
			13	14	15	16	17	18	x	n	s _x
G	2	39.8		10	91	32			15.17	133	.047
	3	44.7			34	147	10		15.87	191	.034
	5	50.6			27	191	33		16.02	251	.031
	6	55.1			9	41			15.82	50	.055
	7	60.2		3	10				14.77	13	.122
	4	47.4*			18	169	17		16.00	204	.029
	8	47.0			32	188	14		15.92	234	.029
G	3	54.6	2	11	65	14			14.99	92	.063
	5	57.8	5	56	16	1			14.17	78	.062
	4	58.5*	2	42	37				14.43	81	.061
Sa	1	39.0	1	17	17	4			14.62	39	.114
	2	41.6		1	5				14.83	6	.166
	4	56.5		12	140	57	2		15.23	211	.038
	5	62.2	2	8	11				14.43	21	.148
	6	55.5**		25	143	88	2		15.26	258	.040
G	1	39.0		2	3	4			15.22	9	.278
	4	56.3			14	12	2		15.57	28	.120
	6	55.4**		1	28	36	2		15.58	67	.071
Sk	4	55.9			14	26	1	1	15.74	42	.097
	5	61.3			11	6	1		15.44	18	.145
	6#	54.7**			8	32	3		15.88	43	.076
E	1	38.8			14	11	5		15.70	30	.137
	3	48.4			3	16	2		15.95	21	.109
	4	55.2		1	36	133	16		15.88	186	.039
	5	61.3		1	68	86	5		15.59	160	.044
	6#	55.2**			19	159	46	1	16.13	225	.036

* city water temperature
 * well water temperature
 * water of low oxygen content during incubation

Wilby (1946), 10 to 14. The observed values for Experiments I, II and III ranged from 13 to 18. For all three experiments the dorsal ray counts are recorded in Table 3 and are shown graphically in Figure 6. The curves are consistent for both the constant temperature and changing temperature experiments with the maximum number of rays in the 45° to 55° F. temperature range. This is opposite to the effect of temperature upon the number of vertebrae. Tāning (1952) reported similar results for experiments with sea trout.

Anal rays

In counting the rays of the anal fin all elements were included. The same argument for using all the elements of the dorsal fin also prevails for the anal fin and, likewise, the num-

ber of anal rays reported for these experiments is greater than reported in the literature.

Jordan and Evermann (1896) list 16 anal rays for the species. Other authors give the following number: Schultz (1931), 15 to 16; Foerster and Pritchard (1935), 16 to 18; Clemens and Wilby (1946), 15 to 19. The observed values for Experiments I, II and III ranged from 16 to 21 (for lots other than F 6 and Sk 6). The counts of the anal rays are tabulated in Table 4 and shown graphically in Figure 7. Maximum values are in the range of 45° to 55° F. with lower values on either side of this range. For the sea trout Tāning (1952) also found that the number of anal rays was greatest at intermediate temperatures.

As with the dorsal rays the maximum number of anal rays occurred in the temperature range of 45° to 55° F.

TABLE 4.—Numbers of anal rays for chinook salmon of Experiments I, II and III

Experiment	Lot	Temperature °F.	Number of fish with anal ray counts indicated in heading								Lot statistics		S.E.
			16	17	18	19	20	21	22	23	x	n	
I	G	2 39.8			15	62	40	2			19.24	119	.06
		3 44.7				45	124	20			19.87	189	.04
		5 50.6			1	51	164	21			19.86	237	.03
		6 55.1				16	27	1			19.66	44	.07
		7 60.2		1	6	4					18.27	11	.19
		4 47.4*			2	85	118	6			19.61	211	.03
		8 47.0			1	63	117	8			19.70	189	.04
II	G	3 54.6		2	18	24					18.50	44	.08
		5 57.8	1	38	43	5					17.60	87	.06
		4 58.5*		5	33	4					17.98	42	.07
III	Sa	1 39.0	1	11	15	6					17.79	33	.13
		4 56.5		9	123	93	11	1			18.46	237	.04
		5 62.2		17	11	1					17.45	29	.10
		6 55.5**		21	167	101	3				18.29	292	.03
	G	1 39.0			7	6					18.46	13	.14
		4 56.3			5	15	9				19.14	29	.12
		6 55.4**		1	23	49	10				18.82	83	.07
	Sk	4 55.9			11	46	8				18.95	65	.06
		5 61.3			8	12					18.60	20	.11
		6# 54.7**			9	54	11	1			19.05	75	.06
	E	1 38.8		1	15	20	2				18.61	38	.10
		3 48.4			3	13	7	1			19.25	24	.15
		4 55.2		1	20	149	82				19.24	252	.03
		5 61.3		15	89	86	25	6			18.63	221	.05
		6# 55.2**			9	19	78	185	69	5	20.82	365	.04

*At city water temperature

**At well water temperature

Water of low oxygen content during incubation

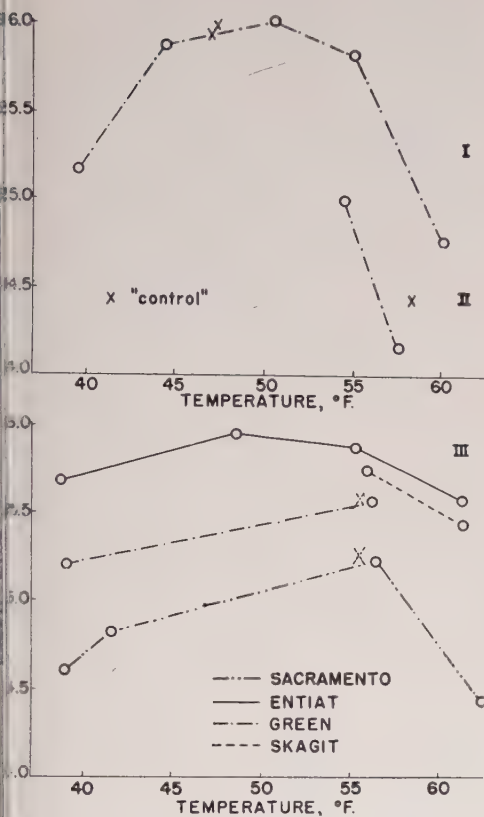


FIGURE 6.—Average number of dorsal rays and the temperature for lots of Experiments I, II and III.

CONCLUSIONS

The lots with the lowest average number of vertebrae and the highest average number of anal fin rays and dorsal fin rays were found to occur at temperatures in the middle portion of the temperature range. This observation is in agreement with the results of experiments by Schmidt (1921) and Tåning (1952) with rainbow trout and Lindsey (1954) with paradise trout.

By contrast the vertebral counts of rainbow trout by Gabriel (1944) and of plaice by Neveig (1950) and the scale counts of rainbow trout by Mottley (1934) were not related to temperature throughout the experimental temperature range.

The difference in the average number of vertebrae, within the same stock, of lots reared at various temperatures was less than the difference in the average number of vertebrae between the four stocks (Experiment III). From these results genotypical variation in vertebral

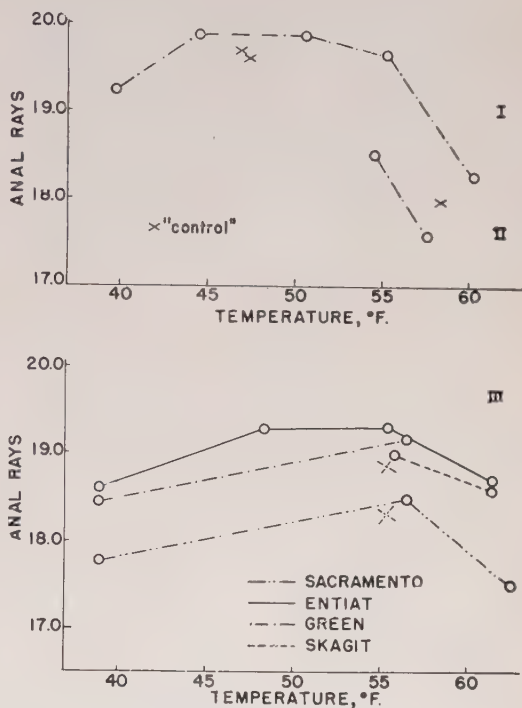


FIGURE 7.—Average number of anal rays and the temperature for lots of Experiments I, II and III.

number appears to be greater than phenotypical variation.

The results of Experiment III conform with the generalization of Gunther and Gill and with Jordan's "law" which state that for the same species the number of vertebrae increases with latitude. The average number of vertebrae in the Sacramento River (California) lots was significantly less than for any of the three Washington rivers. For the lots from the Entiat River, the most "northern" of the streams, there was practically no overlap in vertebral counts when compared to the Sacramento River lots. By Ginsburg's definition the difference was equivalent to a species difference. There is a qualification to this generalization. The assumption is made that the lots for any one river are representative of the population of that river and since the lots for any one river were produced by only 1 to 4 spawning pairs this assumption may not be correct.

The average number of vertebrae per lot for two lots that were inadvertently incubated in water of low oxygen content (3.0 p.p.m.) during the first 21 days of a 46-day egg stage was greater by about two than the average for comparable lots reared at normal oxygen levels. From this observation the following conclusions are made: (1) water of low oxygen content during early embryological development increases the number of vertebrae; and (2) the plastic period for the formation of vertebrae begins before the mid-point of the egg stage. Incubation of lots at low oxygen levels was not a planned part of the experiment.

ACKNOWLEDGMENTS

The experiment reported here is part of a research problem that has been prepared as a graduate thesis. The experiments were conducted under the guidance of Dr. L. R. Donaldson, Chairman of the Supervisory and Reading Committees. Errors and omissions in the thesis manuscript have been corrected from suggestions made by Dr. R. Van Cleve and Dr. A. C. De Lacy, members of the Reading Committee. Valuable aid as to techniques and methods was received from Dr. A. D. Welander and Dr. K. Bonham. An independent count of vertebrae and fin rays was made by Mr. G. Rollesfsen. Chinook salmon eggs were obtained from the Washington State Department of Fisheries and U. S. Fish and Wildlife Service.

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Book Reviews

HOW TO KNOW THE FRESHWATER FISHES. By Samuel Eddy. Wm. C. Brown Co., Dubuque, Iowa. 1957, 253 pp., 615 figs. Spiral bound \$2.75; cloth bound \$3.25.

The requisite tools for identification of freshwater fishes have lagged far behind those provided for other groups of vertebrate animals. Not since the appearance of Jordan and Evermann's *Fishes of North and Middle America* at the turn of the century have the freshwater fishes of the United States been treated in an adequate manual of identification prepared by an ichthyologist. Recourse to regional studies or compilations by non-specialists has been necessitated. Now within a period of a few months a bad situation has been abruptly alleviated by the publication of three comprehensive works aimed primarily at the proper identification of freshwater fishes, all by able ichthyologists. One volume is regional in scope, but Trautman's *Fishes of Ohio* easily ranks as the finest of state ichthyologies and will prove of broad utility. Both George A. Moore's section on fishes in the *Vertebrate Animals of the United States* and Samuel Eddy's *How to Know the Freshwater Fishes* treat all or almost all of the freshwater fishes of the United States and do it well. Strangely, however, the two works are so diverse in their basic approach, Moore emphasizing text keys and distribution, Eddy stressing illustrated keys and drawings of most species, that they complement each other nicely. The nomenclature adopted by Eddy, Moore, and Trautman reveals a number of seeming inconsistencies and disagreements. These reflect the current fluid state of nomenclature and emphasize areas where taxonomic research or communication has been inadequate to permit unified agreement. Despite differences, however, all three authors indicate their alignment with a general trend of the past decade to admit larger, more comprehensive genera, thus emphasizing broader phyletic relationships and devaluing minor structural specializations. For example, none recognizes *Cristivomer*, *Leucichthys*, *Megatomotobus*, *Hyborhynchus*, *Couesius*, *Nocomis*, *Ameiurus*, *Plancerus*, *Lepibema*, *Huro*, *Hadropterus*, or *Poecilichthys*.

Only a few pages of Dr. Eddy's manual are devoted to orientation, discussion of structure, and terminology. The use of body length as distinguished from standard length is unheeded and is apt to contribute to confusion. There are illustrated keys to families and genera and to some species. For some genera, species identification is achieved by reference to figures, characters given in the text, or geography. Over 430 among the 600 odd species treated are illustrated. Wisely, no consideration has been given to subspecies. At best, American freshwater fishes are not always easy to identify even by specialists, and poorly preserved specimens, juveniles, non-typical variants, and hybrids create added problems. Nevertheless, users of Dr. Eddy's guide should, with care, be able to identify accurately a large share of our freshwater (and some euryhaline) fishes.

The figures are in general excellent and often permit identification without recourse to the text. Dr. Eddy's pen has captured the characteristics of

the sunfishes and darters especially well; most instantly recognizable. Even the combination index and glossary is generously illustrated. There are some errors that can be eliminated in subsequent printings. Among the more unfortunate are the misspelling of Chondrichthyes, Osteichthyes, and Characidae. This reviewer prefers to include the tarpon in the family Elopidae and the grayling in Salmonidae instead of placing these forms in separate families, and employs Soleidae instead of Achiridae. Dr. Eddy has produced a most welcome and useful handbook that fills a real need. I urge that it be kept up to date and available for years to come.

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LITERATURE OF AGRICULTURAL RESEARCH. By Richard Blanchard and Harold Ostvold. University of California Press, Berkeley and Los Angeles. 1958. 231 pp. \$5.00.

Despite the agricultural implications of the title, this bibliographic work is of considerable interest to those fisheries workers who are trying to find their way in the maze of scientific literature. Ten pages are devoted to listings, with brief descriptions, of sources of worlds' fisheries literature. Principal emphasis is on commercial fisheries. Listed are bibliographies of bibliographies (reference chasing taken to the third power), abstracting journals, bibliographies and indexes of several kinds, dictionaries and encyclopedias, directories and year books, handbooks and texts, and sources for historical, geographical, statistical, and legal information. In all there are 94 fisheries references, including such bibliographic items as Commercial Fisheries Abstracts, World Fisheries Abstracts, subject index to publications of the now defunct U. S. Bureau of Fisheries and Dr. Carlander's well known "Handbook."

It is easy to find omissions and the authors make a pretense of complete coverage. It is unfortunate, however, that the two very useful cumulative Indexes to the *Transactions* (for 1872-1928 and 1929-1951) are not listed. Nor is the subject index for *Copeia* for period 1913-1954 included.

We should be grateful, however, for the bibliographic job that has been done in this book. It meets the hope expressed by the author in the Preface, that it be considered "a step in the right direction." To fisheries workers this book will all be of value as a guidepost in related fields that they know less well than their own; such fields as food and nutrition, soils and fertilizers, veterinary medicine and economic zoology.

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EFFECTS OF ATOMIC RADIATION ON OCEANOGRAPHY AND FISHES. *National Academy of Sciences — National Research Council Publication No. 551. 1957. Various authors. 137 pages. \$2.00.*

This volume is the report of the Committee on the Effects of Atomic Radiation on Oceanography and Fisheries, one of six committees established by the National Academy of Sciences—National Research Council in 1955 to review broadly the status of knowledge on the biological effects of atomic radiation. The other five committees present the results of view of genetics, pathology, agriculture, food supplies, meteorology, and the dispersal and disposal of radioactive wastes.

Each of the chapters was written by one or more of the committee members, (of whom the reviewer was one) and the over-all content of the book is the consensus of the committee as a whole. Thus, the book is well integrated and there are frequent references from one chapter to another. All together, there are 13 chapters on as many different aspects of the effects of atomic radiation on oceanography and fisheries as follows: General considerations concerning the ocean as a receptacle for artificially radioactive materials; Physical and chemical properties of wastes produced by atomic power industry; Comparison of some natural radiations received by selected organisms; Disposal of radioactive wastes in the ocean; The fission product spectrum in the sea as a function of time and mixing characteristics; Transport and dispersal of radioactive elements in the sea; The effects of the ecological system on the transport of radionuclides in the sea; Precipitation of fission product radionuclides on the ocean bottom by physical, chemical, and biological processes; Ecological factors involved in the uptake, accumulation, and loss of radionuclides by aquatic organisms; Laboratory experiments on the uptake, accumulation, and loss of radionuclides by marine organisms; Accumulation and retention of radioactivity from fission products and other radionuclides by fresh-water organisms; Effects of radiation on aquatic organisms; Isotopic tracer techniques for measurement of physical and chemical processes in the sea and the atmosphere; On the tagging of large masses for the study of physical processes in the oceans; and, Large-scale biological experiments with radioactive tracers.

The committee did a thorough job in gathering and presenting information over a wide range of subjects. Much of that information is fundamental to our knowledge and understanding of the role to be played by radioactive materials in the future. Because many organisms have the innate ability to concentrate certain elements through their metabolic processes, because they apparently are incapable of discerning between the radioactive and the nonradioactive (stable) isotopes of those elements, a new approach to the analysis of physiological processes in plants and animals has been opened. Similarly, many of the physical aspects of the mixing and movements in large water masses are now being studied by means of radioactive tracers. However, the progress of the field of study precludes any hope of definitive work on the subject for many years to come. Much has been accomplished during the past 15 years but there are tremendous amounts of work to be done.

One of the most suitable areas for almost unlimited research is the study of long-term effects of

exposure to low levels of radiation on animal populations. We know the effects of bomb blasts and the effects of the radiation on organisms within a relatively close range of the blast, but we are most ignorant of the effects of long-term low-level exposures. Atomic energy is here to stay just as are the automobile and the airplane. We must learn to live with certain permissible concentrations of radio-materials in the environment (we have been since time out of mind) and it is up to the biologists, and other scientists as well, to determine just what those permissible concentrations are and how they effect animal communities.

The book could have benefited from more information on the role of radioactive wastes in fresh waters. Large rivers, such as the Mississippi and the Ohio, and large bodies of fresh water, such as the Great Lakes, form the natural drainage patterns for some of the most densely populated and industrialized areas in the United States. These areas are likely sites for the construction of atomic power plants. The waste materials from these plants are contained, but their effects, both harmful and beneficial to living organisms, should be determined.

It is a very useful reference for all those interested in the aquatic phases of radiation biology as well as to those interested in physical and/or chemical limnology and oceanography.

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THE SCIENCE OF SKIN AND SCUBA DIVING: *Adventuring with Safety Under Water. Edited by the Editorial Staff of the Conference for National Cooperation in Aquatics. Association Press, New York, 1957. 306 pp., illustrated with line drawings, charts and tables. \$3.95.*

Eleven informative, instructional and interesting chapters by eleven outstanding skin and scuba divers. This text is informative to the most seasoned "free diver" and could serve as an instructional and operational manual for a novice in the science of skin and scuba diving. Illustrative (and often humorous) line drawings depict what to do and what is better left undone in underwater diving and swimming.

The editorial staff has done so well that the reader is unaware that each chapter is by a different author. Various chapters range from the physical requirements and ability of swimmers to the gas laws and human physiology at different water depths and pressures.

Descriptions are given of the different types of free-diving and scuba diving apparatus with remarks on the advantages or limitations of each. Also described are aquatic conditions, especially temperatures and currents, that may be encountered in marine and fresh water diving.

First-aid recommendations are given and notes on how to plan and organize scuba diving expeditions and clubs. Not a technical book, but useful and easy to read.

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Shorter Papers and Notes

Detrimental Effects of Highway

Construction on a Montana Stream

In 1955, it was learned that plans for highway improvement in Granite County, Montana would involve some channel changes on Flint Creek. This stream is a tributary of the Clark Fork of the Columbia River. The fish population in several sections of Flint Creek had been inventoried annually each spring by electric shock census as part of a federal aid investigations project (Montana F-13-R) initiated in 1954.

Flint Creek averages about 20 feet in width, six inches in depth. It has holes up to four feet deep, and has an average flow of about 15 cubic feet per second. In its original condition good trout cover was provided by overhanging willows and undercut banks (Figure 1). Rainbow trout (*Salmo gairdneri*), cut-throat trout (*Salmo clarki*), eastern brook trout (*Salvelinus fontinalis*) and mountain whitefish (*Prosopium williamsoni*) are the game fishes in this study area.

A 230-volt D. C. portable generator, used for fish population census, was efficient at

capturing approximately 90 percent of large sized (six inches total length and over) game fish present in Flint Creek, as indicated by recaptures of tagged trout. Sections of the stream to be shocked were blocked off with 1/2-inch mesh seines placed a measured distance (usually 300 feet) apart.

The new highway construction was begun in the fall of 1956 and continued through the summer of 1957. A bulldozer was used to remove brush, scour the stream bed and straighten approximately 350 feet of the channel of Flint Creek (Figure 2). Such channel changes are common along new highway construction in mountainous terrain and affect many miles of stream each year in Montana.

Nearly the same 300 foot section of stream at the highway construction site was sampled each spring, from 1955 through 1957. Fish taken in 1955 and 1957 were enumerated, weighed, measured and recorded (Table 1). Those taken in 1956 were counted and recorded only as over or under six inches total length. All fish captured were returned alive to the study area. Numbers of large trout captured were 75 and 69 in 1955 and 1956 respectively. Only six large sized trout were found in this section in 1957, after



FIGURE 1.—Flint Creek study area untouched by highway construction.



FIGURE 2.—Flint Creek study area after channel changing by highway construction.

unnel changing phase of the highway construction had been completed.

TABLE 1.—Game fish captured by electric shocker from 300 foot section of Flint Creek, Montana, 1955 and 1957

Species	1955		1957	
	Number	Lbs.	Number	Lbs.
Large-sized fish				
Rainbow and cut-throat trout	68	12.63	6	1.19
Western brook trout	7	3.86	0	0.00
Mountain whitefish	16	2.25	0	0.00
Total large sized fish	91	18.74	6	1.19
Small-sized fish				
Rainbow and cut-throat trout	46	1.32	6	0.26
Western brook trout	6	0.17	2	0.10
Mountain whitefish	1	0.04	0	0.00
Total small-sized fish	53	1.53	8	0.36
Total fish, all sizes	144	20.27	14	1.55

The reductions shown in Table 1 were 94 percent in both numbers and weight of large sized game fish. In small sized game fish (under six inches total length) these reductions were 85 percent in number and 76 percent in weight.

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Water Temperature and Survival of Giant Scallop

Effects of water temperature on spawning and adult survival appear to control abundance of the giant scallop (*Placopecten magellanicus* Melin) in the Gulf of St. Lawrence and limit its distribution there to a narrow depth range. Such effects probably explain the limits of scallop distribution and success throughout its geographic range.

The strength of year-classes of scallops varies greatly in all parts of its range, leading to marked fluctuations in abundance. In the Gulf of Fundy where spawning appears to take place every year, year-class success and abundance of adults about 6 years later seem related to temperature of the water after spawning, apparently through its influence on survival of larval larvae. In certain parts of the Gulf of

St. Lawrence where year-class success is highly variable, water temperatures in some years remain so low that spawning does not take place.

High water temperatures appear directly responsible for some of the sudden mass mortalities of adult scallops reported in the Gulf of St. Lawrence since 1928. Mortalities as high as 90 percent have taken place in periods of 2 to 3 weeks. Laboratory experiments show that scallops living in water between 5 and 20°C. may be killed by temperatures of 21 to 23°C., depending on their previous temperature experience. A sharp thermocline develops in the waters of the Gulf of St. Lawrence in summer above which water temperatures may be between 21 and 22°C. Storm induced oscillations in depth of the thermocline appear great enough to flood scallop beds with the water of lethally high temperature.

High, but sub-lethal water temperatures may also induce mass mortalities indirectly. Scallop mobility is markedly reduced by sudden temperature changes, and while acclimation and adjustments to rising temperatures are relatively rapid (2 or 3 days) adjustment to reduced temperatures is exceedingly slow (over 2 months). If scallop predators adjust more quickly than scallops, rapidly increased mortalities may result from the sudden increase in exposure to depredation. However, mortalities from depredation appear to be less severe than direct temperature mortalities. Unusual abundance of predators has not been found associated with sudden mass mortalities over about 25 percent.

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Dolly Varden Trout with Two Adipose Fins

During August, 1954, a 10.5-inch (fork length) Dolly Varden trout, *Salvelinus malma*, was caught by angling in a narrow feeder stream emptying into a small lake located approximately 25 miles N. E. of Homer, Kenai Peninsula, Alaska. The second adipose fin was situated slightly laterally (right side) and immediately posteriorly to the normal fin. The configuration of both fins was quite similar and each fin appeared to be normal in every respect.

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DEDICATION

This issue of the TRANSACTIONS is dedicated to the memory of Dr. H. S. Davis, a past president of the American Fisheries Society and one of America's foremost authorities on fish culture and fish diseases. The summary of the accomplishments of Dr. Davis, which follows, has been prepared by Dr. Paul R. Needham of the University of California.



H. S. DAVIS

1875 - 1958

H. S. DAVIS

1875 - 1958

The field of fisheries lost one of its most distinguished contributors when Dr. H. S. Davis passed away on July 15, 1958 in Orlando, Florida, at the age of 83. He served as President of the American Fisheries Society in 1932-33.

A colleague of Dr. Eben Cobb, George C. Embody, Henry O'Malley, John Titcomb, and others, he gave unselfishly of his time and effort during the transition period in fisheries when it was passing from what might be termed the fish-cultural stage to the one of modern management concepts as we know it today. With the late Dr. George C. Embody of Cornell University, he conducted some of the first research directed toward perfecting superior strains of fishes. His major work, however, dealt with diseases and parasites of fishes and his *Care and Diseases of Trout* published in 1935, became the most used reference at fish hatcheries throughout the world. His *Culture and Diseases of Game Fishes*, published in 1953, represents his last and most comprehensive publication.

Dr. Davis was born in Oneida, New York. He took the B.S. and Ph.B. degrees at Wesleyan University, going on to Harvard for his Ph.D. After teaching 15 years at the University of Florida, he became Chief of Aquicultural Investigations for the U. S. Bureau of Fisheries, serving in this capacity until his retirement in 1944. He was Chief Fish Pathologist for the Oregon State Game Commission from 1943 to 1947, after which he became Research Associate at the University of California at Berkeley, California.

A quiet, friendly, and unassuming person, he always welcomed new ideas, no matter where they originated. His younger staff members always felt perfectly free to make suggestions and were given strong moral support in their efforts to improve techniques or methods of approach to fishery problems.

In 1938, he authored *Methods of Conducting Stream and Lake Surveys*, which in its time, was the fishery trainee biologist's handbook. He was responsible for the establishment of the experimental fisheries stations at Leetown, West Virginia, Pittsford, Vermont, and Convict Creek in eastern California, which were the predecessors of the many fine, well-equipped fish fish-cultural stations we see today. He pioneered in early experimental dietary work with trout at fish hatcheries and contributed many papers on the nutrition of trout.

Not the least of Dr. Davis' abilities was his use of the English language. For clarity of thought and simplicity of expression, he had few equals in the preparation of scientific papers. His contributions assure him a permanent place in the history of fisheries. His influence in the field and on his students and co-workers will never be forgotten.

